FUZZY TOPSIS AS A DECISION-SUPPORT TECHNIQUE FOR THE DISINFECTION SYSTEM SELECTION IN IRRIGATION WASTEWATER

Gómez-López, MD.

García-Cascales M.S.

Bayo J. Angosto J.M.

Grupo de Gestión y Ayuda a la Toma de Decisión en Proyectos. Universidad Politécnica de Cartagena

Abstract

The reuse of treated wastewater from wastewater treatment plants is an internationally-used practice with a large variety of applications, i.e. irrigation, urban and recreational uses, groundwater recharge, aquaculture, and industrial uses, among others. For all of these, the quality of the water should be taken into account. But it is also important to remark that the environmental and social impact derived from treated wastewater reuse is an intrinsically complex multidimensional process. Therefore, the final decision involves multiple criteria and multiple actors. On many occasions uncertain information is available on social and environmental factors so it is necessary to apply fuzzy tools to assess it. This work presents the use of multicriteria decision through the fuzzy TOPSIS method, applied to six different methodologies concerning the disinfection of treated wastewater prior to its reuse. For this purpose, a set of criteria and subcriteria through a series of pair-wise comparisons have been used with linguistic and non-linguistic information processed by the experts.

Keywords: multicriteria decision making MCDM, Fuzzy TOPSIS Method, Linguistic labels, wastewater reuse.

1. Introduction

Water scarcity in arid and semiarid regions and the increase of its use for agricultural, recreational, and environmental purposes have brought about an important increase in water deficit during recent years; this fact forces us to look for new alternatives, mainly water desalination; and wastewater reuse from wastewater treatment plants (WWTPs), from both urban as well as industrial facilities.

WWTPs are mostly designed to reduce the biochemical oxygen demand (BOD), although this treated water still holds an important number of pathogenic microorganisms. In this sense, water disinfection has proved to be an important tool for the inactivation and destruction of these organisms, in order to preserve both human health and the environment [1].

Although different disinfection techniques can be used, chlorination has been the traditional system employed all over the world for wastewater disinfection. However, chlorine residues and the presence of disinfection by-products (DBPs) have promoted the development and implementation of a number of other technologies. Amongst them, ultraviolet (UV) radiation has come to be the most generalized alternative, with thousands of installations in all countries. This technology also has some disadvantages: the possibility of repairing UV-damaged DNA and the need for an extremely low turbidity in wastewater, otherwise the disinfection procedure would be useless [2]. The combination of both disinfection alternatives, i.e., chlorination and UV radiation, would improve the disinfection process, avoiding the disadvantages of each technique.

Different authors have applied the use of multicriteria decision making (MCDM) methodologies for the resolution of water problems; Carrasquero et al. [3], about water quality; Gómez-Limón and Berbel [4], about water demand; and Simoes et al. [5] water reutilization in Brazil, among others. On the other hand, Abu-Taleb [6], Khalil et al. [7], and Aragonés-Beltrán [8] have used discrete MCDM techniques for water reutilization purposes; and Gómez et al. [9], and Gómez-López et al. [10] have used this tool for the decision of different alternatives affecting the disinfection procedure.

For all these reasons, and taking into account the importance in the decision of the disinfection procedure for wastewater reuse, we have previously dealt with this problem [10]. In that manuscript, we could confirm that the resolution of this problem with crisp numbers could not allow us to distinguish between different alternatives selected for the first and second place. We have tried to resolve this problem by means of fuzzy numbers, which enable a better graduation in the judgments of technical experts. TOPSIS methodology has been implemented with fuzzy numbers for the linguistic labels modulation.

2. Methodology

2.1 TOPSIS Method

The TOPSIS approach is an MCDM for the arrangement of preference to an ideal solution by similarity. It was developed by Hwang and Yoon [11] in 1981, also Zeleny [12] and Lai et al. [13], García-Cascales and Lamata [14], and many others have worked on the topic.

In this study, the TOPSIS method, which is very simple and easy to implement, was used to select the preference order of the alternatives. The MCDM that includes both numeric and linguistic labels can be expressed in a matrix.

The TOPSIS algorithm can be expressed in a series of steps that can be seen in Chen and Hwang [15] and which are summarized below in Figure 1.

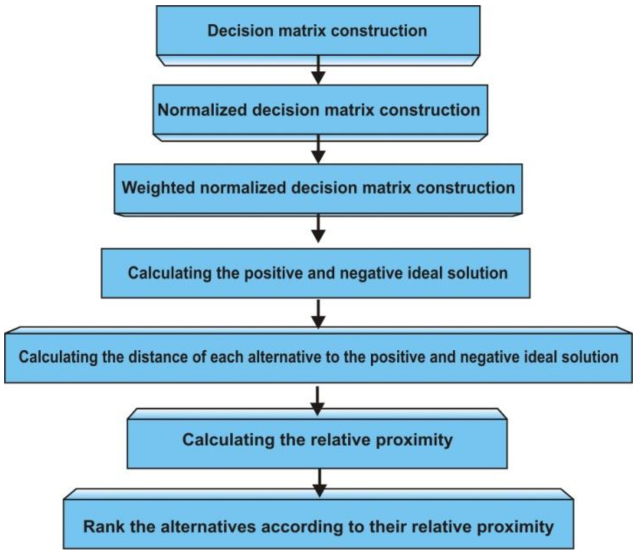

Figure 1. TOPSIS algorithm steps

2.2. Linguistic variable and Fuzzy Sets

Most of the time, the decision-maker is not able to define the importance of the criteria or the goodness of the alternatives with respect to each criterion in a strict way. In general, for the decision-maker it is easier when he/she evaluates judgements by means of linguistic terms.

Since Zadeh [16] introduced the concept of fuzzy set and subsequently went on to extend the notion via the concept of linguistic variables, the popularity and the use of fuzzy sets have been extraordinary. We are particularly interested in the role of linguistic variables, and their associated terms, in this case fuzzy numbers, which will be used in the MCDM.

By a linguistic variable [17, 18, 19] we mean a variable whose values are words or sentences in a natural or artificial language. For example *Age* is a linguistic variable if its values are linguistic rather than numerical, i.e., *young, not young, very young, quite young, old, not very old and not very young*, etc., rather than numbers as 20, 21,22, 23,...

So, a linguistic variable is characterized by a quintuple

$$\left\{X;T\left(X\right);U;G;M\right\} \tag{1}$$

in which

X is the name of the variable,

$T\left(X\right)$ is the term set of X, that is, the collection of its linguistic values

U is a universe of discourse,

G is a syntactic rule for generating the elements of $T\left(X\right)$

and M is a semantic rule for associating meaning with the linguistic values of X.

For decision makers it is generally easier to evaluate using linguistic terms in their judgments. In these cases the concept of fuzzy number is more appropriate than a real number.

So, we identify the linguistic variable with a fuzzy set [20,21,22]. Fuzzy set theory, introduced by Zadeh [16] to deal with vague, imprecise and uncertain problems has been used as a modelling tool for complex systems that can be controlled by humans but are hard to define precisely. A collection of objects (universe of discourse) X has a fuzzy set A described by a membership function fA with values in the interval [0,1].

$$f_A: X \rightarrow [0,1] \tag{2}$$

Thus A can be represented as $A=\left\{f_A\left(x\right);x\in X\right\}$, when fA is the membership function. The basic theory of the triangular fuzzy number is described in Klir [23].

The defuzzification method used is described in [8], when:

$$I_{\beta,\lambda}\left(A_i\right)=\beta S_M\left(A_i\right)+\left(1-\beta\right)\lambda S_R\left(A_i\right)+\left(1-\beta\right)\left(1-\lambda\right)S_L\left(A_i\right) \tag{3}$$

In this way, we have defined a fuzzy number as a function of the three integrals, $S_L(A_i)$, $S_M(A_i)$ and $S_R(A_i)$, when $S_R(A_i)$ represents the upper mean value associated with the inverse function of $f_A^R(x)$, $S_L(A_i)$ is the lower mean value of the $g_A^L(x)$ function and $S_M(A_i)$ is the area of the core of the fuzzy number, $\beta \in [0,1]$ is the index of modality that represents the importance of the central value against the extreme values, and $\lambda \in [0,1]$ is the degree of optimism of the decision maker. We have considered the case in which the three areas have the same weight which would correspond to the neutral decision maker, when $\alpha = 1/2 \; y \; \beta = 1/3$

The calculation process which has been used in group decision making is defined by Keeney and Raiffa [24], Chen and Hwang [15] and Triantaphyllou [25] as the process by which you select the best alternative Ai, i=1,2,...,n with n ≥ 2 by a series of decision-makers or experts Ek, k=1,2,...,r with r ≥ 2 taking into account a number of criteria Cj, j=1,2,...,m with m ≥ 2 with which the different alternatives are evaluated, where n, r and m, are discrete. This paper has used a consistent decision process since the results of each expert were considered in the same proportion in the group decision.

3. Case study

We choose an algorithm based in fuzzy number (García-Cascales and Lamata, [26]) and multicriteria decision support TOPSIS method (Hwang and Yoon [11]; Chen and Hwang [15]) to select the best of six different methodologies concerning the disinfection of treated wastewater before reuse in irrigation. The steps taken are as follows:

1. Identification of the evaluation criteria as finite alternatives.

The decision process scheme is presented in Figure 2. For more details consult (Gómez-López et al. [10].

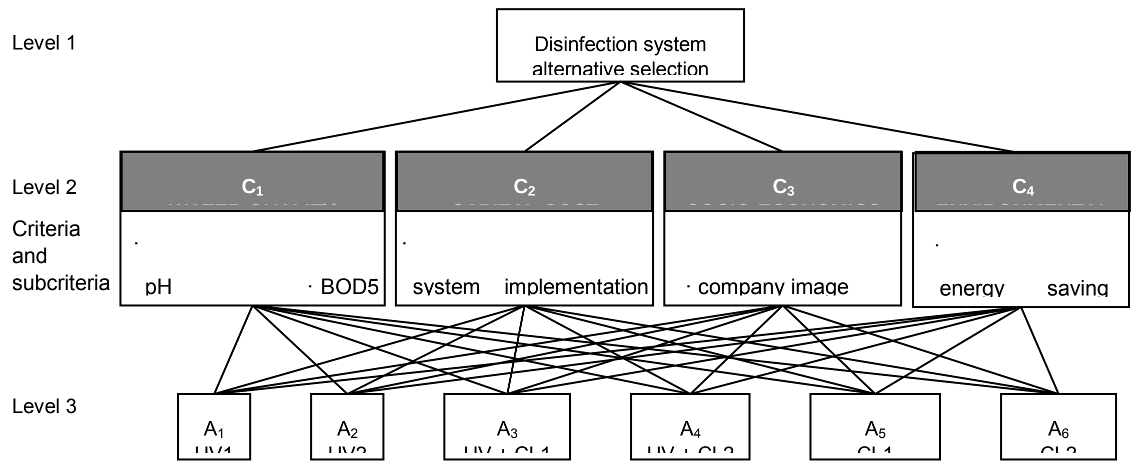

Figure 2. The hierarchical structure of disinfection system alternative selection for treated wastewater reuse for irrigation use.

2. Decision-makers must specify their judgments, using the type 1 linguistic variables explained in Table 1 of the relative importance of each criterion's contribution towards achieving the overall goal.

Table 1 presents the fuzzy number associated to different linguistic labels. These were used for the importance weight of each criterion and subcriterion (type 1) and for the ratings of the alternatives (type 2).

Linguistic label type 1			Linguistic label type 2		
Label	Description	Fuzzy number	Label	Description	Fuzzy number
vL	Very low	[0, 0, 0.1]	vB/vL	Very bad/Very low)	[0, 0, 1]
L	Low	[0, 0.1, 0.3]	B/L)	Bad/Low	[0, 1, 3]
mL	Medium low	[0.1, 0.3, 0.5]	mB/mL	Medium bad/Medium low	[1, 3, 5]
m	Medium	[0.3, 0.5, 0.7]	m	Medium	[3, 5, 7]
mH	Medium high	[0.5, 0.7, 0.9]	mG/mH	Medium good/Medium high	[5, 7, 9]
H	High	[0.7, 0.9, 1.0]	G/H	Good/High	[7, 9, 10]
vH	Very high	[0.9, 1.0, 1.0]	vG/vH	Very good/Very high	[9, 10, 10]

Table 1 - Linguistic variables for the importance weight of each criterion and subcriterion, type 1, and for the ratings of the alternatives, type 2.

Table 2 presents the fuzzy data of the weights that each expert gave to the groups of criteria. In the Annex the weight of qualitative subcriteria and data of quantitative subcriteria are presented in Tables 1 and 2, respectively. The quantitative data are expressed as a triangular fuzzy number. These are defined by the experimental average data and the standard deviation. Thus, the triangular fuzzy number will be defined as a triplet (a, b, c) as follow:

$$(a,b,c) = (\bar{X} - \sigma_x, \bar{X}, \bar{X} + \sigma_x) \tag{4}$$

being $\overline{X}$ the experimental arithmetic average, and σ_x the deviation.

	C1	C2	C3	C4
E1	[0.257;0.345;0.455]	[0.143;0.241;0.409]	[0.086;0.172;0.318]	[0.143;0.241;0.409]
E2	[0.250;0.313;0.385]	[0.139;0.219;0.346]	[0.083;0.156;0.269]	[0.250;0.313;0.385]
E3	[0.257;0.345;0.455]	[0.143;0.241;0.409]	[0.086;0.172;0.318]	[0.143;0.241;0.409]

Table 2. Normalised weights for each group of criterion, according to experts

3. Data obtained from the assessment made by each of the experts with regard to the valuation of each alternative for each of the criteria considered (type 2 linguistic label, Table 1) are presented in Table 3.

As can be seen, in this case two types of labels have been used, which are associated to the same fuzzy number. These were chosen by a physiologic explication, in order for the expert to understand, i.e. a high or low cost and a good or bad company image.

		A1	A2	A3	A4	A5	A6
Expert 1	C11	vG	G	G	m	B	mB
	C21	m	mH	mH	H	mL	m
	C22	m	mH	H	vH	mL	mL
	C31	mG	mG	m	mB	B	B
	C41	L	L	m	m	H	mH
	C42	L	L	mL	m	mH	H
	C43	L	L	m	mH	H	H
Expert 2	C11	G	G	G	mG	mB	m
	C21	mL	m	mH	H	L	mL
	C22	mL	m	mH	H	L	mL
	C31	G	G	mG	m	mB	mB
	C41	L	L	m	mL	H	mH
	C42	vL	vL	L	mL	m	mH
	C43	L	L	mL	m	mH	H
Expert 3	C11	G	G	vG	mB	mB	mG
	C21	H	H	vH	vH	mH	mH
	C22	H	vH	vH	vH	m	H
	C31	vG	vG	G	G	mG	mG
	C41	mH	m	L	vL	m	mL
	C42	vL	vL	mL	mL	H	H
	C43	vL	vL	L	L	L	L

Table 3. Linguistic labels for the assessment of each criterion for each of the alternatives.

4. Construction of the matrix of decision with fuzzy numbers and construction of the associated normalized weighted matrix.
5. Determination of the positive ideal solution and the negative ideal solution and calculation of the separation of each alternative from that solution.
6. Calculation of the relative proximity $\left(\bar{R}_i^a, \bar{R}_i^b, \bar{R}_i^c\right)$ of each alternative to the positive ideal and negative solution by proximity index.

Figure 3 shows graphically the result obtained for the proximity index for each alternative in the decision process for each expert separately and the final result of the group.

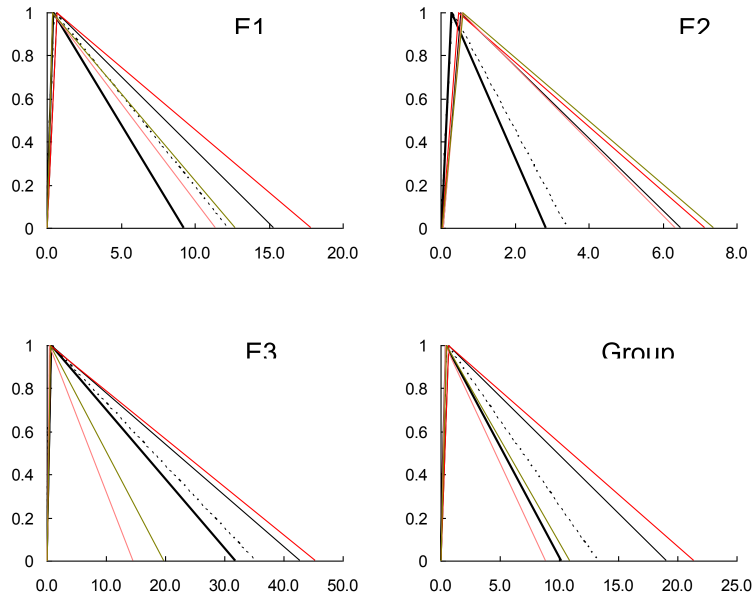

Figure 3. Results on fuzzy numbers of the relative proximity $\bar{R}_i$ of A1 (—), A2 (----), A3 (—), A4 (—), A5 (—) and A6 (—) for each of the experts and for the group.

7. Defuzzification and definition of the preference ordering of alternatives in crisp numbers.

As shown in Figure 3, the final decision with the fuzzy numbers is unclear, due to the overlap of the graphs.

Therefore, it is necessary to use a defuzzification tool. The values obtained in this process for the group decision are presented in Table 4.

Table 4 shows the data of the coefficients of proximity and order of the alternatives obtained for solving the problem directly with crisp numbers (Gómez-López et al. [10]) and the resolution with fuzzy numbers using a later defuzzification.

	Crisp		Fuzzy	
	R	Order	R	Order
A1	0.46	4	2.04	5
A2	0.52	3	2.58	3
A3	0.72	2	3.61	2
A4	0.72	1	3.99	1
A5	0.33	5	1.70	6
A6	0.28	6	2.09	4

Table 4. Results of the coefficients of proximity and order of the alternatives for the group, using crisp numbers (Gómez-López et al. [10]) and fuzzy numbers with defuzzification

It is clear from the results shown in Table 4 that the best alternative will be the fourth one, in both cases.

It is necessary to emphasize that with the calculation using fuzzy numbers it has been possible to distinguish more clearly between alternatives 3 and 4, while with crisp numbers this distinction was quite imperceptible.

4. Conclusions

An analysis with fuzzy numbers has been proposed because the problem has uncertainty in some of the suggested (proposed) criteria, and also in order to seek great accuracy in solving the problem.

The TOPSIS method has been chosen to allow the decision to combine quantitative and qualitative criteria; the use of fuzzy numbers; and linguistic labels. It is true that the classic TOPSIS method (with crisp numbers) could have been used but the results did not offer distinguishable alternatives between A3 and A4.

As happened with the calculation with crisp numbers, the alternative that has come out as the best has been the mixed option of ultraviolet with chlorination between 0.71 and 0.87 ppm, in this case we found that the difference in the coefficient of proximity with the second best alternative was further away.

Although the result obtained is the same, given the small difference between the best alternative and the next, the calculation with fuzzy numbers may have caused a change in the decision.

From the point of view of the problem it would be interesting to implement the decision with fuzzy numbers for other water uses, such as urban or industrial.

Moreover, it would also be interesting to work with experts with different weights on the final decision, in order to increasingly approach the realest solution. For example, in the case of water for irrigation, it would have been interesting to have experts with farmers and representatives of government organs with decision powers.

References

[1] Huertas E., Salgot M., Hollender J., Weber S., Dott W., Khan S., Schäfer A., Messalem R., Bis B., Aharoni A. and Chikurel, H., "Key objectives for water reuse concepts". Desalination, Vol. 218, 2008, pp. 120-131.

[2] United States Environmental Protection Agency. "EPA/832/F-99/064". Office of Water, Washington, D.C. 1999.

[3] Carrasqueño, N., Najul, M.V., and Sánchez, R., "Enfoque multicriterio para la evaluación de la calidad del agua", *Revista de la Facultad de Ingeniería de la UCV,* Vol. 19 (3), 2004. pp. 31-41.

[4] Gómez-Limón, J,A., and Berbel, J., "Multicriteria analysis of derived water demand functions: A Spanish case study", *Agricultural Systems*, 63, 2000, pp. 49-72.

[5] Simoes C.F., Nunes K.R.A., Xavier L.H., Cardoso R. and Valle R. "Multicriteria decisión making applied to waste recicling in Brasil". *Omega,* Vol. 36 (3), 2006, pp. 395-404.

[6] Abu-Taleb, “Aplication of multicriteria analysis to the desing of wastewater treatment ina nationally protected area”, Environmentalñ Engineering and Policy, 2, 2000, pp. 37-46.

[7] Khalila, WA, Shanablehb A., Rigbya P, Kokot S., “Selection of hydrothermal pre-treatment conditions of waste sludge destruction using multicriteria decision-making”, *Journal of Environmental Management*, 75, 2005, pp. 53–64

[8] Aragonés-Beltrán P., Mendoza-Roca J.A., Bes-Piá A., García-Melón M., Parra-Ruiz E., “Application of multicriteria decision analysis to jar-test results for chemicals selection in the physical–chemical treatment of textile wastewater”, *Journal of Hazardous Materials* 164, 2009, pp. 288–295

[9] Gómez, M., Plaza, F., Garrafón, G., Pérez, J. and Gómez M.A. “A comparative study of tertiary wastewater treatment by physico-chemical-UV process and macrofiltration–ultrafiltration technologies”. *Desalination*, Vol. 202, 2006, pp. 369-376.

[10] Gómez-López M. D., Bayo, J., García-Cascales M. S. and Moreno J. M., “Decisión support in disinfection technologies for treated wastewater reuse”. *Journal of Cleaner Production*, Vol. 17, 2009, pp. 1504-1511.

[11] Hwang, C.L y Yoon, K. Multiple Attibute Decision Methods and Applications, Springer, Berlin Heidelberg, 1981.

[12] Zeleny, M. Multiple Criteria Decision Making, McGraw-Hill, New York, 1982

[13] Lai, Y.J, Liu, T.Y y Hwang, C.L. TOPSIS for MODM, European Journal of Operational Research 76 (3), 486-500, 1994.

[14] García-Cascales, M.S y Lamata, M.T. A modification to the index of Liou and Wang for ranking fuzzy number. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems, 411-424, 2007

[15] Chen, S.J y Hwang, C.L. Fuzzy Multiple Attribute Decision Making: Methods and Applications, Springer-Verlang, Berlin, 1992.

[16] Zadeh, L.A. Fuzzy sets, Information and Control 8 338–353, 1965.

[17] Zadeh L.A., “The concept of a linguistic variable and its application to approximate reasoning: Part 1.” *Information Sciences,* 8, 1975, pp. 199-249.

[18] Zadeh L.A., Kacprzyk J. (eds). Computing with Words in Information / Intelligent Systems 1. Foundations. Studies in Fuzziness and Soft Computing, Physica-Verlag (Springer-Verlag), Heidelberg and New York. Vol. 34 1999.

[19] Zadeh L.A., Kacprzyk J., “Computing with Words in Information/Intelligent Systems 2. Applications. Studies in Fuzziness and Soft Computing”. Physica-Verlag (Springer-Verlag), Heidelberg and New York. Vol. 33 1999.

[20] Bellman R.E., L.A. Zadeh., “Decision-making in a fuzzy environment”, Management Science, 17, 1970, pp. 141-164.

[21] Kacprzyk J., Yager R.R., “Linguistic summaries of data using fuzzy logic”, *International Journal of General Systems*, 30, 2001, pp. 133-154.

[22] Kerre E.E.. “The use of fuzzy set theory in electrocardiological diagnostics”, in: M.M. Gupta and E. Sanchez, Eds., Approximate Reasoning in Decision Analysis Amsterdam; North-Holland 1982, pp.277-282.

[23] Klir G.J. Yuan B.," Fuzzy sets and Fuzzy Logic", Prentice Hall PTR, New Jersey e d. 1995

[24] Keeney, R., Raiffa, H., Decisions with Multiple Objectives: Preferences and ValueTradeoffs, Wiley: New York, 1976

[25] Triantaphyllou E. Multi-Criteria decision making methods: A comparative study. The Netherlands: Kluwer Academic, 2000.

[26] García-Cascales, M.S y Lamata, M.T. Un método algorítmico para extender TOPSIS en problemas de decisión con números difusos. ESTYLF Ciudad Real 313-318. 2006

Acknowledgements

This paper has been prepared under the projects, TIN2008 - 06872 - C04-04, which are financed by the DGICYT and Seneca 08824/PPC/08, funded by the Autonomous Community of Murcia, Spain.

Correspondence (for more information contact)

Mª Dolores Gómez López

Grupo de Gestión y Ayuda a la Toma de Decisión en Proyectos

Universidad Politécnica de Cartagena

Paseo Alfonso XIII, 48

30204 Cartagena (Murcia)

Teléfono +34 968 325668

E-mail: lola.gomez@upct.es

Annex

	C11	C21	C22	C31	C41	C42	C43
E1	[0.029;0.055;0.099]	[0.050;0.114;0.256]	[0.064;0.127;0.256]	[0.086;0.172;0.318]	[0.042;0.114;0.315]	[0.018;0.064;0.220]	[0.018;0.064;0.220]
E2	[0.028;0.050;0.084]	[0.049;0.104;0.216]	[0.063;0.115;0.216]	[0.083;0.156;0.269]	[0.073;0.148;0.296]	[0.031;0.082;0.207]	[0.031;0.082;0.207]
E3	[0.029;0.055;0.099]	[0.050;0.114;0.256]	[0.064;0.127;0.256]	[0.086;0.172;0.318]	[0.042;0.114;0.315]	[0.018;0.064;0.220]	[0.018;0.064;0.220]

Table 1anx: Normalised weights for each qualitative subcriterion assigned by each expert

Subcriterion	Alternatives					
	A1	A2	A3	A4	A5	A6
C12: Conductivity (µS/cm)	2647±299	2592±115	2458±190	2490±107	2296±164	2210±280
C13: Turbidity (NTU)	1.3±0.5	1.8±0.7	2.0±0.6	2.8±0.3	5.7±0.9	4.9±0.8
C14: DOD_5 (% reduction)	49.7±8.0	44.4±9.7	25.0±4.2	27.1±5.7	77.5±5.9	87.0±3.2
C15: Chlorides (mg/L)	533.8±96.7	522.3±20.4	463.0±12.8	455.2±26.5	309.4±7.2	299.3±16.8
C16: Total coliforms (% reduction)	96.2±9.0	99.4±5.2	94.5±2.3	91.4±6.2	99.6±7.1	100.0±8.3
C17: CF (% reduction)	97.8±7.1	100.0±6.0	95.0±7.3	95.0±9.2	99.2±5.4	82.6±8.1

Table 2 anx: Numerical values of quantitative criteria, obtained experimentally in the laboratory concerned with its standard deviation