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Applications of ordered weighted averaging (OWA) operators in environmental problems

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Abstract

This paper presents an application of a prioritized weighted aggregation operator based on ordered weighted averaging (OWA) to deal with stakeholders' constructive participation in water resources projects. They have different degree of acceptance or preference regarding the measures and policies to be carried out, which lead to different environmental and socio-economic outcomes, and hence, to different levels of stakeholders' satisfaction. The methodology establishes a prioritization relationship upon the stakeholders, which preferences are aggregated by means of weights depending on the satisfaction of the higher priority policy maker. The methodology establishes a prioritization relationship upon the stakeholders, which preferences are aggregated by means of weights depending on the satisfaction of the higher priority policy maker. The methodology has been successfully applied to a Public Participation Project (PPP) in watershed management, thus obtaining efficient environmental measures in conflict resolution problems under actors' preference uncertainties.

Keywords: OWA operators; stakeholders; decision-making; water resources management.

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1. Introduction

Public participation projects in watershed management has expanded considerably during the last decades, largely in response to the environmental compulsory legislation in many countries (e.g., Peña-Haro et al., 2010; 2011; Molina et al., 2012; Llopis-Albert et al., 2014). For instance, the EU WFD enacts the achievement of a good quantitative, qualitative and/or ecological of all water bodies by a series of measures ranked under the conditions of ecological efficiency, full cost recovery and public participation (EC, 2000).

In order to achieve the environmental and socio-economic objectives the heterogeneous stakeholders' interests must be balanced. Public participation eases the enforceability of measures and policies, because they provide transparency, confidence in institutional actors, consensus among stakeholders, and legitimacy of the river basin management plan (e.g., Llopis-Albert et al., 2015). There are different levels of stakeholders' participation on account of their degrees of influence in the decision-making process, and how they are affected by the measures undertaken. The levels range from information supply (stakeholders are only informed), consultation (only the actors' opinions are considered), to active involvement (actors develop alternatives, identify solutions and take responsibilities).

In this work, stakeholders are divided into three main sets: government (national, regional and local governments, and river basin authorities); experts and opinion formers (advisors and academics, mass-media); and the users of water resources (i.e., water user associations for agricultural, industrial and urban use).

There are several factors that may lead to conflict of interest among actors, which range from the environmental objectives pursued, different rates of socio-economic development for the region, level of engagement and means of participation, and alternative measures to be undertaken.

In accordance with the stakeholders' importance and influence their priority is defined. The government has been defined with the largest weights, the users have the second, while the experts present the smallest weights.

In this paper, the stakeholders' satisfaction in a PPP are analyzed through the ordered weighted averaging aggregation (OWA) operator, although other approaches such as the fuzzy set/Qualitative Comparative Analysis (fsQCA) or structural equation modelling could also be applied (Xu et al., 2014; Berbegal-Mirabent and Llopis-Albert, 2016; Llopis-Albert and Palacios-Marqués, 2016).

OWA operators (Yager, 1988; Yager et al., 2011) and prioritized multi-criteria decision-making problems have been widely used in the literature (e.g., Yager, 2004; Amin and Sadeghi, 2010; Yan et al., 2011).

2. Methodology

In conflict decision-making processes some actors are considered as prior to others. This is performed by taking under consideration their importance and influence and how they bear the measures to be undertaken. The aim is to obtain through prioritized aggregation operators (Yager, 2008; 2009, Wang et al., 2014) a prioritization among stakeholders, and the overall scores of each alternative.

We assume that stakeholders $D = \{D_1, D_2, \cdots, D_n\}$ can be divided into q categories $H_1, H_2, \dots, H_n$; where $H_i = \{D_{i1}, D_{i2}, \cdots, D_{in_i}\}$, D_{ij} is the stakeholder in category H_i, $D = \bigcup_{i=1}^{q} H_i$ and $\sum_{i=1}^{q} n_i = n$. There is also a prioritization among the categories, which entail that $H_1 > H_2 > \cdots > H_q$. The set of alternatives are defined as $X = \{x_1, x_2, \cdots, x_m\}$ and for each alternative x in X and for each stakeholder, the value $D_{ij}(x) \in [0,1]$ expresses the stakeholders' satisfaction or preference. The alternatives are ranked, which present a strict priority order when each priority level is assigned to only one stakeholder (i.e., $n_k = 1$ for $k = 1,2, \dots, q$) while otherwise a weakly ordered prioritization takes place.

According to Yager (2008) the value of $D(x)$ can be determined for alternative x as:

$$D(x) = F\left(D_{ij}(x)\right) = \sum_{i=1}^{q}\left(\sum_{j=1}^{n_j}\omega_{ij}D_{ij}(x)\right) \tag{1}$$

The priority relationship is defined by means of weights ω_{ij}. They are function of x and are associated with a particular ordered position, contrary to the weighted means. In addition, the values of the variables are formerly ordered in a decreasing way.

The satisfaction degree of stakeholders for each priority level can be expressed as:

$$Sat_i = OWA\omega_i\left(D_{i1}(x), D_{i2}(x), \cdots, D_{in_i}(x)\right) = \sum_{k=1}^{n_j}\omega_{ik}b_{ik}(x) \tag{2}$$

where ω_i is the OWA weighting vector associated with each priority category H_i and $b_{ik}(x)$ is the k^{th} largest of $D_{ij}(x)$. The weights satisfy that $\omega_{ik} \in [0,1]$ and $\sum_{k=1}^{n_j}\omega_{ik} = 1$. The weights can be calculated using a wide range of techniques (see, e.g., Yager, 1988; O'Hagan, 1988; Xu, 2005).

The priority induced importance weights (T_i) of each priority level H_i are obtained as follows:

$$T_i = \prod_{k=1}^{i} Sat_{k-1} \tag{3}$$

In which:

$$Sat_0 = 1;\ for\ H_1, T_1 = 1;\ for\ H_2,\ T_2 = T_1 Sat_1;\ for\ H_3,\ T_3 = T_1 T_2 Sat_2$$

The aggregated value for each alternative is calculated through the prioritized OWA (POWA) operator:

$$D(x) = \sum_{i=1}^{q} T_i Sat_i \tag{4}$$

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And the overall score of each alternative is determined by means of:

$$D(x) = \sum_{i=1}^{q} u_i Sat_i \quad (5)$$

where:

$$u_j = \frac{T_i}{\sum_{j=1}^{q} T_j} \quad (6)$$

3. Application to a case study

This methodology is applied to the Jumilla-Villena aquifer (SE Spain), which have a great influence on the agricultural and economic development of the region. This has caused important environmental impacts, such as aquifer over-exploitation, drying out of springs and wetlands, and high concentrations of pollutants (e,g,, nitrates from the fertilizers applied to agriculture) and seawater intrusion. The aquifer has a surface of 338 km^2 and is shared between the Segura and Júcar River Basin Authorities (CHS, 2016; CHJ, 2017). Groundwater reserves are estimated at 1400 hm^3, and accumulated water abstractions from the 1980s is about 1000 hm^3. However, the large uncertainties in hydrological parameters hamper the calculations (e.g, Llopis-Albert et al., 2016; 2016a; 2015; Pulido-Velazquez et al., 2011; Llopis-Albert and Capilla, 2010; 2010a). Groundwater abstractions are around 40 hm3/year with a recharge of 7 hm3/year, i.e., the water system has a disequilibrium of about 33 hm3/year. An important decrease in the piezometric levels of around a 100 meters have been recorded in several wells. This has led to consider the quantitative status of the aquifer to be one of the most important issues in the Segura River Basin Management Plan for the period 2015-2021 (CHS, 2016).

However, these drawdowns have been considerably reduced because the measures undertaken. As a consequence of all these facts, the water system is at risk of not achieving the good quantitative and qualitative status as stated by the EU WFD, thus leading to severe conflicts among stakeholders.

In accordance to the WFD a PPP was performed by the Segura River Basin Authority for the hydrological planning cycle 2015-2021 (CHS, 2016).

As above explained, three different categories of stakeholders with heterogeneous interests are considered:

- Government (H_1): including the national government (D_{11}), the regional and local governments (D_{12}), and the Segura and Júcar water agencies (D_{13}).

- Experts and opinion formers (H_2): including advisors and academics from different fields (hydraulics and environmental sciences, economics, law, NGO's, etc.) (D_{23}).

- Users of water resources (H_3): including water user associations (D_{31}), associations from the tourism sector because its influence in the coastal areas of the SE of Spain (D_{32}), and private companies /e.g., hydroelectric and energy) (D_{33}).

Table 1 presents the stakeholders' satisfaction preference with regard to each alternative. Different weights are assigned to the stakeholders on account of their capacity to influence on the measures to be undertaken. In this sense, the categories are prioritized as follows $H_1 > H_3 > H_2$.

Eventually, the different groups of stakeholders considered in this study are: 3 from different level governments (D_{11}, D_{12}, D_{13}), 3 from experts and opinion formers

(D_{21}, D_{22}, D_{23}), and 3 from water user communities (D_{31}, D_{32}, D_{33}). Each actor provides its satisfaction level or preference to each alternative, thus allowing to obtain the scores $D_{ij}(x)$ with regard to each alternative A_k (k=1,2,…,5).

The Segura Hydrologic Plan for the cycle 2015-2021 entails different alternatives, measures and policies to be carried out that should be discussed by the actors. They include, in order to achieve the environmental and socio-economic objectives, the decrease of over-exploitation, transfer of water resources from other watershed, use of desalination and sewage water plants, government control measurements and regulations, etc. (CHS, 2016).

We consider 5 different alternatives, which entail different levels of priority regarding the environmental and socio-economic objectives, and different measures and policies to achieve those objectives:

-Alternative 1 (A_1): it gives priority to the achievement of the environmental and ecological objectives before the horizon of 2027.

-Alternative 2 (A_2): it tries to balance the environmental and ecological objectives with the socio-economic objectives through the use of external water resources.

-Alternative 3 (A_3): it is similar to alternative A_2 but instead of relying in the use of external water resources it also makes use of desalination plants and sewage treatment plants.

-Alternative 4 (A_4): it gives more priority to the socio-economic objectives in detriment of the environmental ones.

-Alternative 5 (A_5): it is similar to alternative A_1 but entails a high government control, river basin authorities and user's communities for achieving the good status of water bodies.

4. Results and discussion

Table 1 shows the scores $D_{ij}(x)$ obtained by means of meetings, interviews with actors, surveys, expert judgment, mass-media information and reports published by the Segura and Júcar water agencies (CHS, 2016).

Table 1. Satisfaction degree of each stakeholder for each alternative

	D_{11}	D_{12}	D_{13}	D_{21}	D_{22}	D_{23}	D_{31}	D_{32}	D_{33}
A_1	0.9	0.8	0.9	0.9	0.7	0.9	0.6	0.5	0.9
A_2	0.8	0.9	0.8	0.6	0.5	0.6	0.9	0.9	0.5
A_3	0.6	0.6	0.6	0.6	0.5	0.5	0.8	0.9	0.4
A_4	0.7	0.8	0.6	0.7	0.8	0.5	0.9	0.9	0.3
A_5	0.7	0.6	0.7	0.8	0.5	0.8	0.6	0.5	0.9

The weights associated to the OWA operator in Eq. (2) are determined using linguistic quantifiers (Q) (Yager, 2008):

$$\omega_j = Q\left(\frac{j}{n}\right) - Q\left(\frac{j-1}{n}\right), j = 1,2,\dots,n \tag{7}$$

where Q is (Zadeh, 1983):

$$Q(r)=\begin{cases}0, & if\ r<a\\ \frac{r-a}{b-a}, & if\ a\le r\le b\\ 1, & if\ r>b\end{cases}$$

Therefore, the weight vector is $\omega_j=(0.066,0.666,0.268)^T$, with $j=1,2,3$. In this way, the stakeholders' satisfaction for each priority level can be obtained:

$$Sat_1(x_1)=OWA\omega_1\big(D_{11}(x_1),D_{12}(x_1),D_{13}(x_1)\big)=OWA\omega_1(0.9,0.8,0.9)=0.8737$$

$$Sat_2(x_1)=OWA\omega_2(D_{21}(x_1),D_{22}(x_1),D_{23}(x_1))=OWA\omega_2(0.9,0.7,0.9)=0.8469$$

$$Sat_3(x_1)=OWA\omega_3(D_{31}(x_1),D_{32}(x_1),D_{33}(x_1))=OWA\omega_3(0.6,0.5,0.9)=0.5935$$

$$T_1=1;\ T_2=Sat_0\cdot Sat_1=0.8737; T_3=T_2\cdot Sat_2=0.7400$$

By using Eq. (4) the global prioritized aggregated value can be obtained:

$$D(x_1)=\sum_{i=1}^{3}T_iSat_i\ =1\cdot 0.8737+0.8737\cdot 0.8469+0.7400\cdot 0.5935=2.0529$$

By proceeding in the same way:

$$D(x_2)=1.6373;\ D(x_3)=1.1177;\ D(x_4)=1.4536;\ D(x_5)=1.4465$$

This leads the alternatives to be ranked as follows:

$$D(x_1)>D(x_2)>D(x_4)>D(x_5)>D(x_3)$$

We can conclude that after applying a prioritized weighted aggregation operator based on ordered weighted averaging (OWA) the best alternative is A_1, followed by alternative A_2.

5. Conclusions

A methodology based on prioritized OWA operators has been successfully applied to a real case study in the field of water resources. Results show that stakeholders are more concerned about the environmental and ecological objectives (since the aquifer is at risk of not fulfilling the requirements of the WFD) rather than the socio-economic ones. We

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have shown that the methodology is useful when applied to conflict resolution problems under stakeholders' preference uncertainties.

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