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Price water estimation in the Tancítaro Area (Mexico)

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***Abstract*:** T*he state of Michoacán stands out for its fruit production, mainly Hass Avocado (Persea americana). These orchards consume up to 5.2 times more water than the same area of a natural forest. The water used for these orchards belong to the inhabitants of the Upper Basin. The overexploitation and devastation of the forests have provoked the reduction of water availability for agricultural uses. We propose to make an approximation to the price that could be applied if the public administration makes the necessary improvements to ensure availability for farmers, in the future. We have created an artificial water market. Experts in agriculture have expressed their opinion using linguistic label. The use of hesitant fuzzy numbers has allowed the consideration of some kind of hesitance that has appeared during this work. Finally, the use of Ordered Weighting Average has allowed the aggregation of the information. As a result, we have obtained a fuzzy water demand and a fuzzy water supply curve. The intersection of both curves has allowed to get a water price of 0.54 \$ m^{-3}*

Keywords: *Water price, Willingness to pay, Willingness to accept, Hesitant fuzzy number, OWA*

1. Introduction

In the west-central region of Michoacán, Mexico is located the Tancítaro peak. Due to the economic growth and the development, effective management of the environmental services is required as well as rational use of them. It is predicted that by 2030 several large hydrological regions will be found in a critical condition [1]. In Mexico, there is a severe crisis caused by deficient water management, aggravated by both, high rates of deforestation and the loss of the Ecosystem Water Services (representing a country's forests and jungles) [3]

The state of Michoacán stands out for its fruit production, mainly Hass Avocado (Persea americana). Currently, in Michoacán, there is a planted area of 169,939 ha, from which 64,808 hectares are irrigated and 105.13 hectares are rainfed. The total production is 548,150 tons per season [3] and since 2018, the great economic growth has generated a positive impact on the regional economy, increasing the producers' income, as well as direct and indirect employment [4].

These orchards consume about 1,800 l/plant/month, consequently, a hectare of avocado containing 156 trees can consume up to 5.2 times more water than the same area of a natural forest with a density of 677 species per ha. The growth of orchards and their economic benefits forces the change from forest to agricultural land and the intensive use of agrochemicals [5].

The region of Tancítaro peak, with an elevation of 3,800 m., is one of the most important hydrological regions in the state due to the production of avocado whose main destination is exportation. Here, about 30 million m^3 of water are reported annually, thus benefiting the agricultural activities and domestic use of the inhabitants [6]. The overexploitation and devastation of the forests have provoked the reduction of water availability for agricultural uses. It is expected that the water valuation improves the use efficiency of the water [6].

We are aware of the difficulty that entails making this type of assessment. On many occasions, the responses portray a wish rather than an opinion. In other words, a water buyer tends to indicate a low price when interviewed to avoid paying a higher real price in the future. For these reasons, we believe that the introduction of subjectivity will make it possible to express opinions in a better way. As a result, the use of Fuzzy Logic is proposed for better treatment of subjectivity. Fuzzy set theory, firstly introduced by Zadeh [7], has been widely used in several research fields.

Although it is extremely useful, it must be considered that when groups of people are faced with decision-making problems, they tend to "hesitate" between different alternatives, making it difficult to get the final decision. That appears, not because we have a unique solution with a membership degree (fuzzy set) or a margin error (intuitionistic fuzzy sets) but because we hesitate between a set of alternatives and it is impossible to reach a consensus solution. In these cases, it is more reasonable to provide the set of alternatives [8]. For instance, in front of a certain valuation, some Decisions Makers (DMs) can provide the value 0.4, others 0.5, and others 0.8. If they cannot agree, the set of three elements can be represented by a hesitant fuzzy element (HFE).

Furthermore, the paper will introduce a methodological proposal for the quantification equilibrium price of the water employing HFE, and, in the aggregation of subjective information, a very common aggregation method is the ordered weighted averaging (OWA) operator introduced by Yager [9].

In this work, given the increasingly pressing water shortage in the Tancítaro area, we propose to make an approximation to the price that could be applied if the public administration makes the necessary improvements to ensure availability for farmers, in the future. For this purpose, experts representing the stakeholders have expressed their opinion through linguistic labels in an artificial market created to determine the equilibrium price. The use of fuzzy logic and HFES allows better treatment of the information provided by the experts. Finally, the use of OWAs and the confidence assigned to each expert allows graduation of the results according to different degrees of optimism or pessimism.

2. Material and Methods

Next, we will proceed to the estimation of the water demand and supply curves, whose intersection will allow obtaining the equilibrium point.

To estimate the supply curve, a group of J experts administrators of hydraulic sources from CONAGUA and OOPAS were asked to provide its willingness to pay a series of prices for water $P=\{P_1,P_2,...,P_P\}$ to ensure water availability in the future in the Lower and Middle basis of the river. Each price will have valuated using linguistic labels such as totally disagree, strongly disagree, disagree, etc. (Table 1). Each of the elements of the table will be assigned a membership function (from zero to one, according to it). However, some experts hesitate between several alternatives. That is why the use of Hesitant Fuzzy Numbers become especially suitable to incorporate the opinions facilitate by the experts for each price.

TABLE I. Values assigned to the linguistic labels

Linguistic label	**μ_i**
1 Totally disagree	0.00
2: Strongly disagree	0.20
3: Disagree	0.40
4: Neutral	0.60
5: True	0.80
6: Very true	1.00

Definition 1. [10,11]. Let X be a fixed set, a hesitant fuzzy set (HFS) on X is in terms of a function that when applied to X return a subset. To be easily understood, we express the HFS by a mathematical symbol

Where $h(x)$ is a set of some value in $[0,1]$, denoting the possible membership degrees of the element $x \in X$ to see the set E. For convenience, we call $h = h(x)$ a hesitant fuzzy element (HFE) $E = \{(x, h(x)) / x \in X\}$

Next, in order to aggregate the information provided by the set of n expert hesitant fuzzy weighted averaging (HFWA) are defined in order to be able to aggregate the opinion given by the experts

Definition 2. [12]. Let $h_j(j=1,2,...,n)$ be a collection of HFEs. A hesitant fuzzy weighted averaging (HFWA) operator is a mapping $H^n \rightarrow H$ such that

$$\mathrm{HFWA}(h_1, h_2, ..., h_n) = \oplus_{j=1}^{n}(\omega_j h_j) = \bigcup_{\gamma_1 \in h_1, \gamma_2 \in h_2, ... \gamma_n \in h_n} \left\{1 - \prod_{j=1}^{n}(1-\gamma_1)^{\omega_j}\right\} \quad (1)$$

Where $\omega = (\omega_1, \omega_2, ..., \omega_n,)^T$ is the weight vector of $h_j(j=1,2,...,n)$ with $\omega_j \in [0,1]$ and $\sum_{j=1}^{n} \omega_j = 1$

To simplify the way we obtain the supply curve, and considering that the aggregation holds a high number of elements, in particular, if expert j hesitate between l_{ij} alternatives for each price ($P_1, P_2, ..., P_P$), the HFWA will have a total number of $l_i = \prod_{j=1}^{n} l_{ij}$ elements for each price i. The aggregation of the resulting HFE will be done using Ordered Weighting Average (OWA).

Definition 3 [13,14]. An ordered weighted average (OWA) is defined as a mapping of dimension n, $F: R^n \rightarrow R$ that has an associated weighting vector W of dimension n, $W^T = [w_1, w_2, \dots w_n]$, such that $w_j \in [0,1]$ and $\sum_{j=1}^{n} w_j = 1$, with

$$f(a_1, a_2, \dots, a_n) = \sum_{j=1}^{n} w_j \cdot b_j \quad (2)$$

Where b_j is the j-th largest of a_i.

In this way, it is possible to obtain a membership function for each price, that is, the membership function of each willingness to pay, and it can be considered as the water demand function.

The Pico de Tancítaro is made up of 16 hydrological basins together representing 678.1 km^2. They are not large bodies of water, rather, they are low flow runoff between 100-200 $m^3 s^{-1}$, underground hydrography, and permeability are medium. So users take advantage of the water through retention or deep excavation. Thus, the study of water demand in the avocado belt focuses on users of the Upper Basin and users of the Lower Middle Basin. As a result, we have proceeded in a similar way to obtain the supply function. On this occasion, they ask about the price that they will be willing to receive for the resource they have, so they will begin by asking for the lower prices for which they agree to share the water resources.

According to the present model, there will be a price whose demand and supply with the same membership function and it will represent the maximum price at with the farmer (Lower and Middle Basin) will buy water and the minimum price at which the owner of the resources (the inhabitant of the Upper Basin) will share the water

3. Results

Table 2 shows the responses of the consulted experts for the willingness to pay (for the first group) and Table 3 give the willingness to accept of the inhabitants of the High Basin.

TABLE II. Experts opinions for willingness to pay

	Willingness to pay						
Expert	0.15	0.3	0.45	0.6	0.75	0.9	1.05
1	1	1	{0.8;1;1}	{0.4;0.8;1}	{0;0.5;0.6}	{0;0.2;0.4}	{0;0;0.2}
2	1	1	1	0.8	{0.6;0.8;0.8}	0.4	0
3	1	1	1	0.8	{0.8;0.8}	{0.6;0.8}	{0.2;0.4}
4	1	{0.6;0.8}	{0.2;0.4}	{0;0.2}	0	0	0
5	{0.4;0.6}	{0.2;0.4}	{0;0.2}	{0;0.2}	0	0	0
6	1	1	1	0.4	0.2	0	0

TABLE III. Experts opinions for willingness to accept

	Willingness to pay						
Expert	0.15	0.3	0.45	0.6	0.75	0.9	1.05
1	{0;0.1}	{0;0.2;0.3}	{0.4;0.4;0.5}	{0.8;0.9}	1	1	1
2	0	0	0	{0;0.2}	{0.4;0.6}	{0.8;0.9}	1
3	0	0	0	0	{0.4;0.5}	{0.6;0.6}	{0.8;0.9}
4	0	0.6	0.8	1	1	1	1
5	0	0.2	0.4	0.6	0.8	1	1
6	0	0	0	0.2	0.4	0.8	1

Table 4 shows the aggregation of the expert's opinions. As some experts have hesitated between several alternatives, the aggregation presents several values. For instance, for price 0.3, the aggregation of the membership function of the WTP is $\mathrm{HFWA}_{\mathrm{demand}} = \{1,1,1\}$, that is, in all the cases the obtained membership is one and the aggregation for the WTA is $\mathrm{HFWA}_{\mathrm{supply}} = \{0.15, 0.19, 0.21\}$, that is, fluctuate between 0.1 and 0.2.

TABLE IV. Willingness to pay: HFWA and weights for OWA

WTP	0.15	0.3	0.45	0.6	0.75	0.9	1.05
HFWA	{1;1}	{1;1;1;1}	{1;1;1;1;1; 1;1;1;1;1; 1;1}	{0.48;0.5;0.5; 0.52;0.58;0.6; 0.6;0.62;1;1; 1;1}	{0.32;0.38;0.32; 0.42;0.47;0.42; 0.4;0.45;0.4}	{0.17;0.25;0.17;0.25;0.17; 0.25;0.21;0.29;0.21;0.29; 0.21;0.29;0.26;0.33;0.26; 0.33;0.26;0.33}	{0.03;0.06;0.03;0.06; 0.03;0.06;0.03;0.06; 0.03;0.06;0.03;0.06; 0.07;0.1;0.07;0.1; 0.07;0.1}
Weights	{0.5;0.5}	{0.25;0.25; 0.25;0.25}	{0.08;0.08;0.08; 0.08;0.08;0.08; 0.08;0.08;0.08; 0.08;0.08;0.08}	{0.17;0.15;0.14; 0.13; 0.11;0.1; 0.08;0.07;0.01; 0.01;0.01;0.01}	{0.19;0.17;0.19; 0.07;0.02;0.07; 0.12;0.05;0.12}	{0.13;0.08;0.12;0.08;0.11; 0.08;0.08;0.03;0.07;0.03; 0.06;0.03;0.03;0.01;0.02; 0.01;0.02;0.01}	{0.1;0.05;0.1;0.05; 0.1;0.05;0.1;0.05; 0.1;0.05;0.1;0.05; 0.03;0.01;0.03; 0.01;0.03;0.01}

TABLE V. Willingness to accept (WTA): HFWA and weights for OWA

WTA	0.15	0.3	0.45	0.6	0.75	0.9
HFWA	{0;0.02}	{0.15;0.19;0.21}	{0.34;0.34;0.34}	{1;1;1;1;1;1}	{1;1;1;1; 1;1;1;1;1; 1;1;1}	{1;1}
weights	{0.67;0.33}	{0.5;0.33;0.17}	{0.33;0.33;0.33}	{0.17;0.17;0.17;0.17; 0.17;0.17}	{0.08;0.08;0.08;0.08; 0.08;0.08;0.08;0.08; 0.08;0.08;0.08;0.08}	{0.5;0.5}

The aggregation of these values has been done using OWAs. Tables 4 and 5 shows the used OWAs for the obtained HFWA. It is clear that the number of weights for each price (WTP or WTA) is the number of elements of the HFWA. For this purpose, and considering that the aggregation of the HFE gives much more importance to the high membership functions, a digit depending of the order position has been allocated to each element of the HFE. When two items present the same order position, they were assigned the order number of the first one. The assigned weight coefficient is the quotient between the order position and the sum of all assigned numbers. They are represented in the table above for both the case of WTP and WTA

Figure 1 shows the equilibrium price of the water as a result of the intersection of the previously calculated demand and supply functions. For each Willing to Pay price, a membership function has been obtained using the HFWA and OWAs, as well as for each Willing to Accept price. The results have been summarised in Figure 1, where the axis x is the willing to pay/accept provided to the experts, and the axis y is the membership function obtained.

This intersection allows obtaining an equilibrium price of 0.54 \$ m^{-3}, with a membership function is 0.74. The shape of these supply and demand curves depends on the attitude towards risk of the experts consulted [15]. It should also be noted that a greater membership function of the price obtained indicates weaker preference uncertainty.

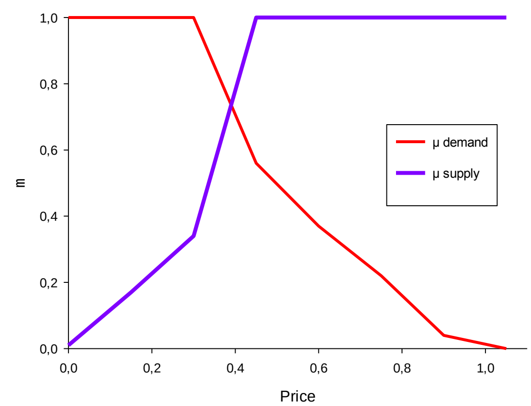

Fig. 1. Water demand and supply

4. Conclusions

The main objective of this work has been to determine an equilibrium price for water in the Tancítaro area. For this purpose, the water users in the Lower and Middle Basin area (denser avocado fringe) have expressed the maximum price they would be willing to pay to ensure a continuous supply of water. In the same way, the inhabitants of the protected area (High Basin) have expressed their opinion about the minimum price required by them to share their water resources.

The fuzzy logic has been introduced in the way the experts express their opinions, using linguist labels. The use of HFE and OWA have increased the flexibility of the model since it allows the experts not only to answer in a dichotomous way (yes or no), but also introduced the hesitation and graduate their opinions. Finally, the use of OWA has allowed the aggregation of the obtained HFE.

The intersection of the demand and supply functions has allowed obtaining the equilibrium price of 0.54 \$$m^{-3}$, with a membership function is 0.74. The final membership obtained is quite high, so the uncertainty of the price is weak.

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