ASSESSMENT OF WATER AVAILABILITIES IN THE TANCÍTARO AREA THROUGH THE FUZZY WILLINGNESS TO PAY

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ABSTRACT

The Tancítaro peak is located in the State of Michoacán in Mexico. The current situation of unsustainable consumption of water resources can lead the region to a critical situation if adequate measures are not taken. An improvement in water management involving paying for the use of these resources could improve the situation. This work aims to propose a model allowing obtaining an equilibrium price of the use of water in the Tancítaro area. For this, experts will be consulted among the users of the water and experts among those who currently the right to use it, that is, inhabitant of the reserve area. The use of the Fuzzy logic will allow them to express their willingness to pay and collect data, not in a dichotomous way, but by grading their opinions. The use of Ordered Weighted Average (OWA) will allow the aggregation of these opinions bearing in mind different degrees of optimism or pessimism. The results obtained show an equilibrium price of $ 0.49 m^{-3}*. It should be noted that these are preliminary results and the main objective of the work is the presentation of a methodological proposal.*

KEYWORDS

OWA, Water demand function, Water supply function, Willingness to accept, Willingness to pay.

1. INTRODUCTION

The management of Ecosystem Water Services, from an economic and environmental perspective, allows creating the context to generate the necessary conditions, based on organizational policy, aimed at achieving sustainable and comprehensive development [1, 2]. 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 [3]. 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) [4, 5, 6]

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The economic valuation of water resources plays an important role in two aspects: demand management and distribution for its different uses. Optimized management of water resources requires decisions based on economic efficiency, social equality and, above all, ecological sustainability. The values of water resources depend on the quality, location, reliability of access, and availability among others [6].

The state of Michoacán stands out for its fruit production, mainly Hass Avocado (Persea americana). Back in the eighties, the total percentage occupied by fruit trees was only 42%, representing 21,241 ha, and by 2009 the percentage increased to 55% (103,602 ha). The state contributes 10% to the national agricultural Gross Domestic Product (GDP) and agriculture represents 7% of the total state's GDP, establishing itself as the main economic activity in some regions and municipalities [7]. 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 [8] 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 [9]. According to De la Tejera et al. [10] more than 47 thousand direct and 187 thousand indirect jobs have been created since then. To sum up, this activity generates annually around $ 30,265,787.40 [11].

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 [12].

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. The municipality of Tancítaro is part of this avocado strip [13]. The avocado is the source of the development for approximately 39,783 inhabitants, distributed in 81 towns and communities. This region is one of the most important areas of the country for its production [14]. Here, about 30 million m^3 of water are reported annually, thus benefiting the agricultural activities and domestic use of the inhabitants [13]. 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 [13, 14, 15].

From an economic logic, the resources' exploitation implies the scarcer the resources, the higher the price would have to be paid for their use. Then, the objective will consist on assessing the economic contribution to irrigation in agricultural systems through the payable provision for the obtained benefits [16,17]. Several methodologies have been used for the valuation of environmental goods, such as the willingness to pay (WTP) or to accept, contingent valuation, travel costs methodology or hedonic prices, among others. In general, these methodologies are based on the user's opinions, in which it is no possible to introduce the subjectivity. Several studies have addressed the willingness to pay for water, such as [18] concerning the Savegre River in Costa Rica, where the cost per opportunity methodology was applied [19] focusing on the Yamuna River, New Delhi. In Mexico, Soto [20] used the contingent valuation method to estimate the benefits of the comprehensive project for the sanitation of Alto Atoyac in Puebla. Sanchez [21], in the Apatlaco River calculated the WTP to improve the water quality of the Apatlaco river basin, or Rodríguez and García [22] studied in the Guayalejo Basin in the south of the state of Tamaulipas.

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 to pay a higher real price in the future. For these reasons, we believe that the introduction of subjectivity will make it possible to express opinions to a better way. As a result, the use of Fuzzy Logic is proposed for a better treatment of the subjectivity. Furthermore, the paper will introduce a methodological proposal for the quantification equilibrium price of the water employing Fuzzy Logic, particularly, in the aggregation of subjective information. The use of fuzzy logic introduces a better treatment of the expert's opinions allowing to graduate in them. However, so far, it has not allowed the graduation of the respondent optimism or pessimism degree. A very common aggregation method is the ordered weighted averaging (OWA) operator introduced by Yager [23]. The OWA operator and its extensions have been used in a wide range of applications [24-29].

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 its opinions through linguistic labels in an artificial market created to determine the equilibrium price. The use of fuzzy logic allows a better treatment of the information provided by the experts. Finally, the use of OWAs and the confidence assigned to each expert allows a 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.

2.1. Water demand function

In order to estimate the supply curve, a group of J experts has been selected and asked about their willingness to pay a series of prices for water $P=\{P_1,P_2,...,P_P\}$ to ensure water availability in the future. The expert set are administrator of hydraulic resources (CONAGUA) and Organismo Operador de Aguas (OOAPAS) municipal of Tancítaro, Michoacán. In the same way, we have tested the willingness to accept for the people who had the availability of the water in the reservation area. Prices have been presented in ascending way, so that $P_i < P_{i'}, i < i'$. If experts agree to pay for the use of the water, they will be asked if they are willing to pay P_1 \$ m^{-3}. If they are not, the final price would be 0 \$ m^{-3}, and if they are willing to pay P_1, they would be asked for his willingness to pay for a price P_2. If the answer is negative, the maximum price would be P_1 and if it is positive, they would be asked for the next price and so on. Given the subjectivity in each answer, it is accepted that the respondent does not respond with a dichotomous answer (yes / no), but rather that they do so according to 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).

Table 1. Values assigned to the linguistic labels

Linguistic label	μ_j
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

From this information, it is possible to obtain the water demand function. For this purpose, three different assumptions have been considered

1. Using average means.
2. Assigning different degrees of optimism and pessimism, based on the opinions provided by experts through OWAs.
3. According to the confidence degree generated by each expert.

2.1.1. Using average means

All experts are equally important. In this way, the price that expert j (WTP_j) would be willing to pay for water can be obtained as:

$$WTP_j^1 = \sum_{i=1}^{P} \Delta P_i \cdot \mu_{ij} \quad (1)$$

Being μ_{ij} the membership function assigned by expert j to price i and $\Delta P_i = P_i - P_{i-1}$, that is, the increase that occurs in each new price provided to the expert to express his willingness to pay, over the previous one. In this way, a series of prices has been obtained representing the price that each expert would be willing to pay $WTP^1 = \left\{ WTP_1^1, WTP_2^1, ..., WTP_p^1 \right\}$.

In this way, it is already possible to obtain the water demand function since the price offered by each expert is available. The curve will be obtained:

- The abscissa axis $P = \{P_1, P_2, ..., P_P\}$ will be made up of the prices initially provided to the experts.
- The ordinate axis, the membership function of each P_i, $\mu^1(P_i)$, is obtained by the quotient between the number of experts n_i who were not willing to pay a price WTP_j equal to or lower than P_i and the total number of experts who answered (J).

$$\mu^1(P_i) = \frac{n_i}{J} \quad (2)$$

2.1.2. Assigning different degrees of optimism and pessimism, based on the opinions provided by experts through OWAs.

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

$$f(a_1, a_2, \ldots a_n) = \sum_{j=1}^{n} w_j \cdot b_j \quad (3)$$

Where b_j is the jth largest of the a_i.

The essence of OWA [23] is the rearrangement of the elements or arguments, causing aggregation in the a_j not associated with a weighting w_j but with the placement order instead.

The weights of expression (3) has been obtained by ordering the prices obtained from the opinions given by the experts (WTP_j) and assigning 1 to the highest, 2 to the second, etc. The weight assigned to position j is, $2j/((J+1)J)$, that is, the quotation between the digit assigned to position the WTP price of expert J in descending order over the total sum of digits (sum of the numbers 1, 2,…, J). This value will be weighted by α factor representing the degree of optimism or pessimism. The highest positive α values correspond to a greater optimism degree, and the lower α values (even negatives) represent a higher pessimism degree.

$$\omega_j^p = \left[\frac{2\cdot j}{(J+1)\cdot J}\right]^{\alpha} \quad (4)$$

To obtain a weights sum equal to 1, the previous weights will be normalized, dividing them by the total sum of weights.

$$\omega_j = \frac{\omega_j^p}{\sum_{j=1}^{J}\omega_j} \quad (5)$$

In this way, it is possible to obtain the water demand function since the price offered by each expert is available. The curve will be obtained as:

• The abscissa axis, $P=\{P_1,P_2,...,P_P\}$ will be formed by the initial prices

• The ordinate axis, the membership function of each WTP_i, $\mu^2(P_i)$ is obtained as the sum of the weights assigned to each of the experts who provided WTP_j lower or equal to P_i.

$$\mu^2(P_i) = \sum_{j=1}^{J}\omega_j \,/\, WTP_j \le P_i \quad (6)$$

2.1.3. According to the confidence degree of each expert.

In this case, each price is weighted according to the importance assigned to each expert. Each of them was assigned a previous probability ρ_j^* (from 0 to 1) depending on the credibility that they generate. Finally, these probabilities are normalized dividing each of them by the total sum of probabilities.

$$\rho_j = \frac{\rho_j^*}{\sum_{j=1}^{J}\rho_j^*} \quad (7)$$

In this way, it is possible to obtain the water demand function since the price offered by each expert is available. The curve will be obtained:

• The abscissa axis $P=\{P_1,P_2,...,P_P\}$ will be formed by the initial prices

• The ordinate axis indicates the membership function of each WTP_i, $\mu^3(P_i)$, the sum of the probabilities assigned to each expert who obtained a WTP_j lower or equal to each of the prices indicated on the abscissa axis $P=\{P_1,P_2,...,P_P\}$.

$$\mu^3(P_i) = \sum_{j=1}^{J} \rho_j \,/\, WTP_j \leq P_i \qquad (8)$$

2.1.4. Water demand function

It will be obtained aggregating the membership functions obtained for each of the three previous methods

$$\mu_i^S = \alpha\mu^1(P_i) + \beta\mu^2(P_i) + \gamma\mu^3(P_i), \text{ with } \alpha,\beta,\gamma \geq 0 \text{ and } \alpha+\beta+\gamma = 1 \qquad (9)$$

Where α is the importance assigned to the supply curve obtained considering all the experts the same importance, β considering the optimistic or pessimistic attitude of the demand curve and γ the importance assigned to the demand functions based on the probabilities assigned to each expert.

2.2. Water supply 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 100-200m^3 s^{-1}, underground hydrography and permeability is 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. Three alternatives will also be used, that is, considering that all experts have the same importance, using OWAs to assign different degrees of optimism and pessimism, and depending on the degree of confidence generated by each expert.

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 higher prices. In this case, the increase indicated in the expression (1) refers to the price reduction provided to the experts in each phase.

2.3. Equilibrium price

The equilibrium point is defined by the intersection of both curves. The equilibrium point will be given by a price p_i and a membership function. The former price p_0 will be the maximum value that a farmer will be willing to pay to obtain water and the minimum that the owner of the resources (inhabitant of the protected areas) will be willing to receive for sharing water resources.

3. RESULTS

3.1. Water demand function

Table 2 shows the responses of the consulted experts. The first column indicates the expert number, the second the degree of confidence of each expert. The following columns indicate the willingness to pay for each of the offered prices. Thus, expert 1, who deserves a degree of confidence of 0.7 indicates that he or she is willing to pay 0.5 and 0.30 $ m^{-3} of water. However, as the price increases, his willingness to pay decreases. For 0.45 $ m^{-3} the expert expresses the opinion with (0.8) and for 0.6 with the expression disagrees (0.4), and for the rest of the prices it indicates that he or she is totally disagreeing (0). A similar methodology has been used in other works such as Brotons & Sansalvador [30]. The willingness to pay of the first expert is obtained as:

$$WTP_1 = 0.15 \cdot 1 + 0.15 \cdot 1 + 0.15 \cdot 0.8 + 0.15 \cdot 0.4 + 0.15 \cdot 0 + 0.15 \cdot 0 + 0.15 \cdot 0 = 0.48$$

That is, multiplying the successive increases in each of the prices by the valuation made by the expert for each price. Last column orders the experts by their willingness to pay in descending order.

Table 2. Willingness to pay

		Willingness to pay								
Expert	**Confidence**	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**	**0.9**	**1.05**	**WTP**	**Order**
1	0.70	1.0	1.0	0.8	0.4	0.0	0.0	0.0	0.48	6
2	0.60	1.0	1.0	1.0	1.0	0.8	0.4	0.0	0.78	3
3	0.10	1.0	1.0	1.0	1.0	0.8	0.6	0.2	0.84	2
4	1.00	1.0	0.6	0.2	0.0	0.0	0.0	0.0	0.27	8
5	0.20	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.09	10
6	0.90	1.0	1.0	1.0	0.4	0.2	0.0	0.0	0.54	5
7	1.00	1.0	1.0	0.8	0.2	0.0	0.0	0.0	0.45	7
8	1.00	1.0	1.0	1.0	0.8	0.6	0.2	0.0	0.69	4
9	0.30	1.0	1.0	1.0	1.0	1.0	1.0	0.7	1.005	1
10	0.70	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.12	9

Next, the weights of each expert are shown in Table 3 in three different ways. The first one was obtained assigning equal importance to each expert (average), the second using OWAs: the weight of each expert was obtained according to the opinion expressed in the previous table (WTP), where the WTP were obtained according to expressions (4) and (5), and considering $\alpha = 0.8$. In this case, experts who expressed higher prices were overweighed and the experts who express lower prices were underweighted. OWAs had also been used to estimate unknown values, for example in Sansalvador & Brotons [31]. In the final way, the weight of each expert has been assigned according to the allocated probability and has been obtained according to expression (7).

Table 3. Weights for willingness to pay

Expert	Average	OWA	Probability
1	0.100	0.095	0.108
2	0.100	0.138	0.092
3	0.100	0.152	0.015
4	0.100	0.063	0.154
5	0.100	0.026	0.031
6	0.100	0.110	0.138
7	0.100	0.080	0.154
8	0.100	0.124	0.154
9	0.100	0.165	0.046
10	0.100	0.046	0.108

Membership functions are shown in Table 4. For each WTP, the sum of the weights assigned to each expert who has express that the price to be paid was equal to or lower to the one shown in the first column Table 4. The added value has been obtained by assigning 0.2 to the “average”, 0.4 to the OWA, and 0.4 to the corresponding probability. Las column of Table 4 shows the demand function. Similar weightings have been used in works such as Sansalvador & Brotons

[31] where a new method for the economic evaluation of the ISO 9001 certification was developed.

Table 4. Membership functions for willingness to pay

WTP	Answers	μ average	μ OWA	μ probability	μ weighted average
0.00	10	1.00	1.00	1.00	1.00
0.15	8	0.80	0.93	0.86	0.88
0.30	7	0.70	0.86	0.71	0.77
0.45	7	0.70	0.86	0.71	0.77
0.60	4	0.40	0.58	0.31	0.44
0.75	3	0.30	0.46	0.15	0.30
0.90	1	0.10	0.17	0.05	0.10
1.05	0	0.00	0.00	0.00	0.00

3.2. Water supply function

Similarly, Table 5 shows the willingness to accept the prices for sharing their available water resources.

Table 5. Willingness to accept

		Willingness to accept								
Expert	**Confidence**	**0.15**	**0.3**	**0.45**	**0.6**	**0.75**	**0.9**	**1.05**	**WTP**	**order**
1	0.8	0.0	0.0	0.4	0.8	1.0	1.0	1.0	0.42	6
2	0.6	0.0	0.0	0.0	0.0	0.4	0.8	1.0	0.72	2
3	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.8	0.78	1
4	1.0	0.0	0.6	0.8	1.0	1.0	1.0	1.0	0.24	8
5	0.0	0.0	0.2	0.4	0.6	0.8	1.0	1.0	0.45	4
6	0.2	0.0	0.0	0.0	0.2	0.4	0.8	1.0	0.69	3
7	0.3	0.0	0.0	0.2	1.0	1.0	1.0	1.0	0.42	5
8	0.1	1.0	1.0	1.0	0.8	0.6	0.2	0.0	0.36	7
9	0.3	0.7	1.0	1.0	1.0	1.0	1.0	1.0	0.05	10
10	0.7	0.2	1.0	1.0	1.0	1.0	1.0	1.0	0.12	9

The weights allocated to each expert are shown in Table 6

Table 6. Expert Weights for willingness to accept

Expert	Average	OWA	Probability
1	0.100	0.095	0.200
2	0.100	0.152	0.150
3	0.100	0.165	0.000
4	0.100	0.063	0.250
5	0.100	0.124	0.000
6	0.100	0.138	0.050
7	0.100	0.110	0.075
8	0.100	0.080	0.025
9	0.100	0.026	0.075
10	0.100	0.046	0.175

Finally, assigning weights (0.2, 0.4, 0.4) to (α, β, δ), that is, to the memberships obtained by each of the three methodologies (average, OWA and probability), it is possible to obtain the results shown in the last column of Table 7 (μ weighted average), representing the water supply curve.

Table 7. Membership functions for willingness to accept

WTP	Answers	μ average	μ OWA	μ probability	μ weighted average
0.00	0	0.00	0.00	0.00	0.00
0.15	2	0.20	0.07	0.25	0.17
0.30	3	0.30	0.14	0.50	0.31
0.45	7	0.70	0.54	0.80	0.68
0.60	7	0.70	0.54	0.80	0.68
0.75	9	0.90	0.83	1.00	0.91
0.90	10	1.00	1.00	1.00	1.00
1.05	10	1.00	1.00	1.00	1.00

3.3. Equilibrium Price

Figure 1 shows the equilibrium price of the water as a result of the intersection of the previously calculated demand and supply functions. This intersection allows obtaining an equilibrium price of 0.49 $ m^{-3}, with a membership function is 0.68. The shape of these supply and demand curves depends on the attitude towards risk of the experts consulted [32]. It should also be noted that a greater membership function of the price obtained indicates weaker preference uncertainty.

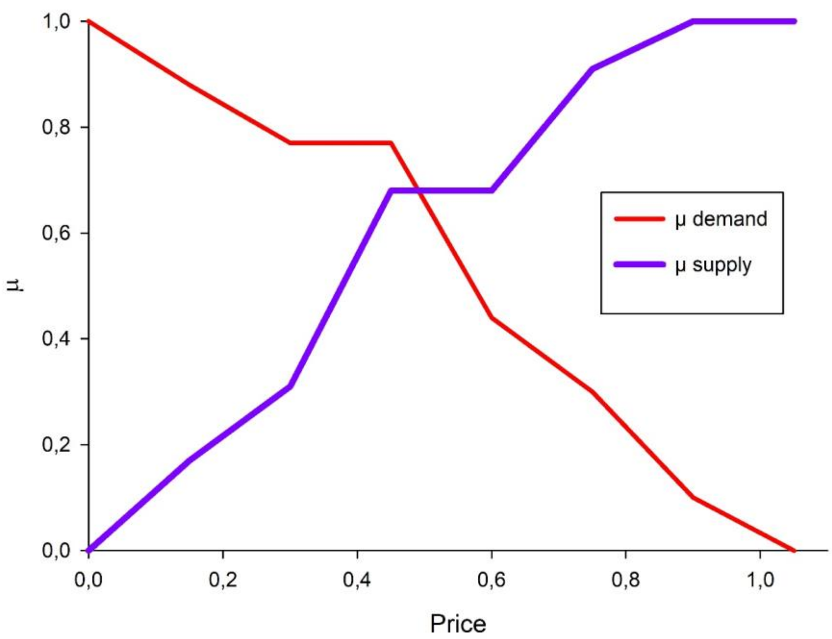

Figure 1. Equilibrium price

The obtained results are in line with those obtained by Rodríguez and García [22], who analyzed the water services payment in sugar cane in the Guayalejo Basin in the state of Tamaulipas, concluding that the price of water could be $ 0.39 m^{-3}. On the other hand, Chávez and Mancilla

[33] proposed a water rate applied to water users in the Pixquiac River, in Veracruz, Mexico, for which the opportunity cost method was used to assign value to the forest, obtaining a price of $ 0.473 m^{-3} (see Figure 2). Other works show different willingness to pay, mainly due to the peculiarities of each area. For example, Barrantes [34] in the Savegre river in Costa Rica applied the cost per opportunity methodology and obtained a value of US $ 0.0010 m^{-3}. In Mexico, Rodríguez and García [22] studied in the Guayalejo Basin in the south of the state of Tamaulipas, how they have been benefited from the water coming from the "Heaven Biosphere Reserve, obtaining $ 0.39 m^{-3}. Finally, Chávez and Mancilla [33] proposed a water tariff applied to water users in the Pixquiac river, in Veracruz obtaining a value of $ 0.473 m^{-3}.

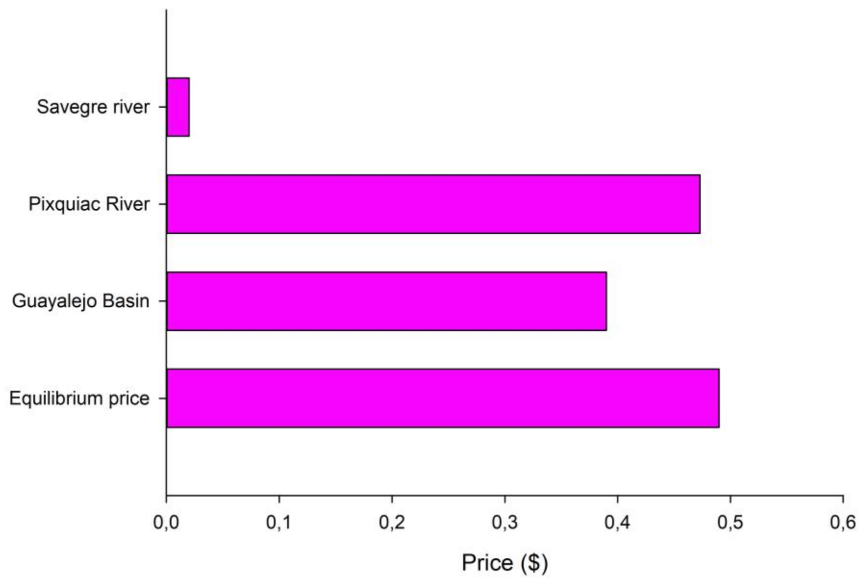

Figure 2. Comparison prices

It should be noted that the application of this methodology has allowed

- The determination of an equilibrium price by creating an artificial market
- The experts to grade their opinions regarding each price with the inclusion of linguistic labels.
- The introduction of OWAs allows graduation the final result according to different degrees of optimism or pessimism in the model
- The introduction of probabilities to each of the experts can improve the quality of the estimation because not all experts deserve the same trust, either because of their knowledge, or because of their interest in obtaining results that are positive for them.

We are aware that it is only an approximation, mainly because on numerous occasions, experts indicate their willingness to pay, something quite different is that if they had to pay, they would actually do it. Therefore, the introduction of fuzzy numbers and OWA extensions should improve the accuracy of the estimation.

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 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 importance assigned to each expert has been considered in two ways, assigning a probability to each expert according the confidence degree in each one as well as just considering their provided values and aggregating them according several degrees of optimism or pessimism.

The fuzzy logic has been introduced in the way the experts express their opinions, using linguist labels. This methodology increases the flexibility of the model since it allows the experts not only to answer in a dichotomous way (yes or no), but also to graduate their opinions.

The intersection of the demand and supply functions allows obtaining the equilibrium price. We are aware that it is a preliminary work and final values may vary significantly compared to those offered in this work, but this paper aims to offer a new methodology applicable cases in which there is no market and it is necessary to create an artificial one to obtain the equilibrium price.

We want to point out that this is a preliminary work and we have used only probability OWAs, OWAs and means, but we are working in the application of some OWAS extension to the water demand and supply, such as induced OWAs. Anyway, the use of intuitionistic fuzzy numbers as well as hesitant fuzzy numbers will improve the quality of our research.

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