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FARMER WILLINGNESS TO PAY FOR IMPROVED IRRIGATION WATER QUALITY AND PRODUCE INNOCUOUS FOODS IN IRRIGATION DISTRICT 003 TULA, HIDALGO

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ABSTRACT

Irrigation district 003 Tula, Hidalgo, is an example of wastewater irrigation in Mexico; however, it results in greater pollution for the environment, farmers, and consumers. The aim of this work was to determine farmers' willingness to pay (WTP) for treated, better-quality water, thus producing innocuous products. A sample of 104 farmers was obtained through simple randomized sampling. The contingent valuation method was used, with two econometric limited dependent variable models, where the interest is primarily in the probability of a response to a binary indicator. The non-linear adjusted binary response models were logit and probit. The best model, according to the log pseudolikelihood, Akaike information criterion, pseudo-R-squared criteria, and the number of correctly predicted cases, was the logit model. The results indicate that education (22.6 %) and income levels (20.3 %) have positive effects on WTP, whereas the opposite occurred with the fee (-0.026 %), the number of economic dependents (-11 %), and the number of hectares planted (-4.2 %). If the farmer considers that there are risks to the health of consumers of foods produced with untreated residual waters, the WTP increases by 11 %. The logit and probit models produced an average WTP of MXN 1649.18 and 1685.08, respectively. The reuse of wastewater requires compliance with acceptable and required quality standards for crops to produce healthy foods that protect the health of farmers and consumers.

Keywords: contingent valuation, logit, probit, residual water, Mezquital Valley.

INTRODUCTION

Economic growth, population growth, and urbanization are catalysts of water pollution. Reusing wastewater for agriculture is common around the globe. However, its treatment is rare in many countries (Contreras *et al*., 2017). Worldwide, two-thirds of the wastewater applied is not treated (Trinh *et al*., 2013). Its agricultural use ranges from 1.5 to 6.6 %, with 4.5 to 20 million ha irrigated globally, with China, Mexico,

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Egypt, India, Indonesia, Iran, and Pakistan standing out. In Mexico, it is estimated that 70 000 and 190 000 ha are irrigated with treated and untreated wastewater, respectively (Sato *et al*., 2013).

It is estimated that high-income countries treat approximately 70 % of all wastewater produced; medium-high-income countries, 38 %; medium-low-income countries, 28 %; and low-income countries treat only 8 % (WWAP, 2017). The countries with the highest amount of wastewater use are China, Mexico, and the USA, with 14.8, 4.4, and 7.6 million m^3 of water a day, respectively, but in the first two cases, the wastewater is untreated. The most important countries in terms of reusing treated wastewater are the USA, Saudi Arabia, and Egypt, with 7.6, 1.8, and 1.7 million m^3 of water a day, respectively (Jiménez and Asano, 2008).

In developing countries, the highest proportion of recycled water is used in agriculture, whereas in developed nations, it is used for urban activities (Brissaud, 2009). In Israel, 75 % of recycled water is used for irrigation agriculture in 19 000 ha. In Kuwait, agricultural irrigation with recycled water accounts for 25 % of the total irrigated surface. In India, Egypt, and Vietnam, approximately 73 000, 42 000, and 9000 ha are irrigated with wastewater, respectively (Chen *et al*., 2013). In France and Italy, wastewater treated for agricultural irrigation covers over 3000 and 4000 ha, respectively (Angelakis *et al*., 2003). In Spain, 79.2 % of the volume of treated wastewater is reused in agriculture (Iglesias-Esteban and Ortega-de Miguel, 2008).

Mexico is second in the world in terms of wastewater used in agriculture with 4.4 million m^3 of water a day, followed by Egypt and Syria with 1.9 and 1.1 million m^3 of water a day, respectively (Jiménez and Asano, 2008). The water system of the Mezquital Valley in Hidalgo, Mexico, is the world's largest and oldest example in terms of untreated wastewater use for agricultural irrigation (Lesser *et al*., 2018). More than 90 000 ha of plantations are irrigated with untreated wastewater from Mexico City, which are distributed in the agricultural irrigation districts of Tula, Ajacuba, and Alfajayucan. The high availability of wastewater has placed farmers in a comfort zone where the treatment of this water is viewed as a threat (Durán-Álvarez *et al*., 2021).

Irrigation plays an important part in the Mezquital Valley due to the scarcity of fresh water, weather conditions, low rainfalls, a higher demand for water by tourism and other sectors, and the increase in the availability of wastewater from Mexico City (Contreras-Román, 2018; García-Salazar, 2019). Wastewater use in irrigation district (ID) 003 Tula dates back more than 100 years ago, with an annual volume of reuse of 1780 million m^3 (56.6 $m^3 s^{-1}$) (Jiménez *et al*., 2005). Its use has led to a physical and chemical degradation of the soil, which influences agricultural productivity. The presence of toxic metals in the region is a risk to human health and the environment (Cornejo-Oviedo *et al*., 2012). Wastewater contains a high pollutant load composed of organic material, metals, bacteria, and detergents, which can lead to public health issues (García-Salazar, 2019), as well as an increase in diarrheal diseases in children (Contreras *et al*., 2017).

Masterplan DR 003 mentions that the chemical composition of wastewater reduces the lifespan of hydro-agricultural infrastructure (floodgates, dams, farm intakes), which must be replaced at least every three years. The gases produced by wastewaters cause the corrosion of structures like culverts and tunnels (CONAGUA, 2005). Farmers, communities, and consumers are at risk due to the harmful components of untreated wastewater. The use of wastewater for irrigation can cause considerable damage to public health and the environment. Its use in agriculture causes externalities for both public health (through the consumption of agricultural products irrigated with wastewater) and the environment (since it constantly pollutes underground water and soil and causes an unpleasant odor) (Wichelns and Qadir, 2015).

The crops sprayed with wastewater can be contaminated with heavy metals, including arsenic, cadmium, lead, and mercury, causing serious health problems, such as osteoporosis. These metals enter the human and animal bodies not only through the intake of vegetables but also by the inhalation of polluted soils (Kesari *et al*., 2021; Qadir *et al*., 2010). Consequently, farmers, agricultural workers, their families, and the consumers of crops irrigated with wastewater are more prone to suffer parasitic diseases (Weldesilassie *et al*., 2009).

Some studies have been carried out on the willingness to pay (WTP) for the improvement of the drinking water service in Mexico (Valdivia-Alcalá *et al*., 2022; Briseño and Macedo, 2021), but there are no studies on WTP for the implementation of irrigation with treated wastewater in an ID or an aquifer. Therefore, the aim of this investigation was to estimate the WTP of farmers in ID 003 Tula, Hidalgo, for better-quality water to understand the factors that impact their will to improve the water they already use and produce innocuous and better-quality crops. The hypothesis is that farmers in ID 003 Tula Hidalgo are willing to pay for better-quality water to irrigate their crops and thus avoid worrying about the health of consumers.

MATERIALS AND METHODS

The contingent valuation method was used, which implies directly asking people how much they would pay in case a hypothetical change was to take place in the future state. A question was asked regarding the WTP, and socioeconomic data was requested in order to describe the interviewee (socioeconomic characteristics such as age, education, income, and gender). Likewise, matters regarding attitudes and beliefs were incorporated, such as stances regarding environmental policies (Young and Loomi, 2014).

The interviews were conducted on the farmers of ID 003 Tula, Hidalgo, between July 5 and 25, 2024. The sample was obtained with the simple randomized sampling method (Anderson *et al*., 2008; Lind *et al*., 2012), using the following formula:

$$n = \pi(1-\pi)\left(\frac{Z}{E}\right)^2$$

where n is the sample size, Z is the standard normal value corresponding to the desired level of trust of 95 % (z = 1.96), π is the proportion of the population (0.5), and E is the maximum tolerable error (9.6 %). The number of users of the ID was 37 267, out of which 57.6 % are commonly owned (ejido) and 42.4 % are small-scale properties. The final sample was of 104 farmers interviewed.

In this study, the dependent variable is dichotomic (binary), where one indicates farmers are willing to pay (a "yes" response) and zero means they are not (a "no" response). Two models were formulated: one logit and another probit (Zegeye *et al*., 2023), in which the probability of paying for better water quality is estimated as follows:

$$P_i = \frac{1}{1 + e^{-(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}} = \frac{e^{(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}}{1 + e^{(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}}$$

where X_1 is the variable fee, X_2 is the education level, X_3 is income, X_4 is the number of economic dependents, X_5 is the number of hectares planted by the farmer, and X_6 is a dichotomic variable of the response to the question "Do you consider there is a health risk in consumers for eating produce irrigated with wastewater?" where a value of one is assigned to an answer "yes" and zero to the answer "no."

The probability of not paying for better quality of water was calculated as follows:

$$1 - P_i = \frac{1}{1 + e^{(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}}$$

The odds ratio of paying relative to the probability of not paying is expressed as follows:

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}}{1 + e^{-(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)}} = e^{(\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\beta_4X_4+\beta_5X_5+\beta_6X_6)} \quad (1)$$

Applying a natural logarithm, L_i is obtained to linearize the parameters:

$$L_i = ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6$$

To estimate the parameters of the model, the maximum likelihood method was used with the statistical software Stata 16:

$$L_i = ln\left(\frac{P_i}{1 - P_i}\right) = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + u_i$$

where u_i corresponds to the error term; that is, factors that affect the WTP but are not explicitly included in the model.

To obtain the farmers' mean WTP for better-quality water to produce innocuous and higher-quality foods, the following formula was used:

$$DAP_{media} = \frac{\sum_{i=1}^{n} \frac{\beta_0 + \beta_2 X_{2i} + \beta_3 X_{3i} + \beta_4 X_{4i} + \beta_5 X_{5i} + \beta_6 X_{6i}}{\beta_1}}{n} \quad (2)$$

RESULTS AND DISCUSSION

All the farmers surveyed were men, with an average age of 57, out of whom 91.3 % are married and the rest, single. In terms of land ownership, 50 % owned small-scale lands, while the rest was commonly owned (ejidos). Maize was planted by 61.5 % of farmers, followed by alfalfa (24 %), beans (11.5 %), and chili peppers (2.9 %). Regarding education levels, 16.3 % of farmers have not completed elementary school, 36.5 % have completed elementary school, 37.5 % have middle school, 7.7 % have high school, and 1.9 % have a university degree. Farmers with an income of MXN 5000 made up 1 % of those surveyed, 72.1 % have incomes of MXN 5000 to 10 000, 24 % make between MXN 10 000 and 15 000, and 2.9 % make between MXN 15 000 and 20 000.

Out of the 104 farmers surveyed, 69.23 % expressed a positive stance regarding their WTP for better-quality recycled water, which represents fewer environmental impacts on the crops and on the health of farmers and consumers. The education level had a positive effect, with 54.2 and 20.8 % of those who completed elementary school and high school having a positive stance, respectively. Meanwhile, 61.1 % of those with an income between MXN 5000 and 10 000, and 33.3 % of those between MXN 10 000 and 15 000 had a positive attitude (Table 1). The farmers surveyed that are willing to pay

Table 1. Frequency of the variables of the willingness to pay (WTP), education level, and income of the farmers interviewed in irrigation district 003 Tula, Hidalgo, Mexico.

WTP	Education level	Frequency	%	Income level	Frequency	%
Yes	Elementary, incomplete	9	12.5	< 5000	1	1.4
	Elementary, complete	15	20.8	5000–10000	44	61.1
	High school	39	54.2	10 000–15 000	24	33.3
	Media superior	7	9.7	15 000–20 000	3	4.2
	Professional	2	2.8			
No	Elementary, incomplete	8	25.0	< 5000	0	0
	Elementary, complete	23	71.9	5000–10000	31	96.9
	High school	0	0	10 000–15 000	1	3.1
	Media superior	1	3.1	15 000–20 000	0	0
	Professional	0	0			

for an improvement in irrigation water quality have 1–6 economic dependents, out of which 15.3 % have one dependent, 26.4 % have two, 27.8 % have three, and 20.8 % have four.

In terms of the hectares planted, farmers with a positive attitude towards their WTP have 1–8 ha planted. Those with three (28.8 %), four (26.4 %), five (15.3 %), and two hectares (11.1 %) stand out. Out of the total of farmers, 59.7 % consider that irrigating with wastewater has effects on the health of consumers and had a positive response to the WTP.

In the logit and probit models, all parameters were statistically significant according to the statistic *z*. The global statistical significance of the Wald chi-squared model was lower than 1 % for both models. However, the best, according to the log pseudolikelihood, Akaike Information Criterion (AIK), pseudo-R-squared, and the number of correctly predicted cases, was the logit model (Table 2).

Table 2. Results of the coefficient estimations of the models evaluating the willingness to pay (WTP) of farmers in irrigation district 003 Tula, Hidalgo, Mexico.

WTP	Logit	Probit
Fee	-0.004***(0.001)	-0.002***(0.001)
Education level	3.300***(1.022)	1.717***(0.422)
Income level	2.969***(1.062)	1.772***(0.559)
Dependents	-1.606***(0.365)	-0.902***(0.167)
Hectares planted	-0.607**(0.300)	-0.324**(0.154)
Consumer health	1.371*(0.847)	0.710*(0.433)
Constant	-2.184(2.422)	-1-475(1.223)
Log pseudolikelihood	-29.730	-30.299
Wald chi^2(6)	26.56***	38.28***
Akaike information criterion	73.461	74.598
Pseudo R^2	0.537	0.528
Correctly predicted	88.46%	86.54%
Observations	104	104

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Standard error in parentheses.

To interpret the models, the odds ratios (Equation 1) and the marginal effects (dy/dx) of each variable were calculated. The variable fee had a marginal effect of -0.026, which means that for every MXN increase, the WTP decreased by 0.026 %. The marginal effect for the education level showed that, for every additional level of education, WTP increased by 22.598 %. The marginal effect of income showed that when the incomes of farmers increased, WTP rose by 20.333 %. When the number of economic dependents increased by one, the WTO decreased by 10.999 %. If the farmer's planted surface increased by 1 ha, the WTP decreased by 4.156 %. Finally, if the farmer considered that there are risks for the health of the consumer of products irrigated with untreated wastewater, the WTP increased by 11.042 % (Table 3).

Table 3. Marginal effects and odds ratio of the variables used in the evaluation of the willingness to pay (WTP) of farmers in irrigation district 003 Tula, Hidalgo, Mexico.

	Logit			Probit		
Variable	*dy/dx*	%	Odds ratio	*dy/dx*	%	Odds ratio
Fee	-0.000	-0.026	0.996	0.000	-0.032	0.998
Education level	0.226	22.598	27.118	0.280	28.032	5.567
Income level	0.203	20.333	19.480	0.289	28.939	5.885
Dependents	-0.110	-10.999	0.201	-0.147	-14.723	0.406
Hectares planted	-0.042	-4.156	0.545	-0.053	-5.295	0.723
Consumer health	0.110	11.042	3.940	0.129	12.941	2.035

In order to obtain the mean WTO, equation (2) was used and values of MXN 1649.18 and 1685.08 were obtained using the logit and probit model, respectively. On average, the producer would be willing to pay those amounts per hectare irrigated with better quality water in DR 003 Tula.

The variable with the greatest effect on the WTP of farmers for the use of treated wastewater was education. Farmers with higher education levels are considered as having access to information sources on the treatment of wastewater, such as the internet, journals, and news (Deh-Haghi *et al*., 2020; Lazaridou *et al*., 2019). The income level of farmers had a positive relation with WTP, in which the higher the income (regardless of whether the farmer has other income sources), the higher the probability of paying more for better-quality water to irrigate their fields. However, the opposite is true with the number of economic dependents, since more economic dependents means a smaller budget available to buy other goods and services not related to the family, such as paying more than what they already pay for the irrigation service.

Out of the total of farmers surveyed, 60.6 % considered that there is a risk involved in consuming products irrigated with wastewater, and 77.9 % considered there are environmental risks involved in irrigating with untreated wastewater. The perception of health risks has impacts on the willingness to use treated wastewater (Deh-Haghi *et al*., 2020; Khanpae *et al*., 2020). The use of untreated or partially treated wastewater for irrigation involves the risk of contracting diseases, both for farmers and their families, as well as consumers. The diseases prevalent among farmers include hookworm infection, ascariasis, and giardiasis. Diseases related to the consumption of raw vegetables include shigellosis, cholera, typhoid fever, and diarrhea (Leonel and Tonetti, 2021).

CONCLUSIONS

The willingness to pay (WTP) for improved irrigation water quality revealed that education level, income level, and consumer perception of health had positive effects, whereas the fee, the number of the farmer's economic dependents, and the number of hectares planted had negative effects. Therefore, the most appropriate mechanism is to raise awareness and educate farmers about health risks for both themselves and consumers so they increase their WTP for higher-quality irrigation water and consequently manage proper wastewater treatment for agricultural use.

The farmers of the irrigation district are worried about risks and therefore are willing to pay for better quality water. The treatment and reuse of wastewater is an option to face water scarcity problems, as well as contributing to its sustainable use. Reusing requires that these waters have the required quality for crops to produce healthy foods that guarantee the health of farmers and consumers.

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