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Articles

Estimation of the willingness to pay in two aquifers in Baja California, Mexico

Estimación de la disponibilidad a pagar en dos acuíferos en Baja California, México

Lázaro S. Elizondo[1], ORCID: https://orcid.org/0009-0005-0374-0594

Alonso Aguilar-Ibarra[2], ORCID: https://orcid.org/0000-0003-1030-713X

Robert H. Manson[3], ORCID: https://orcid.org/0000-0001-9732-8894

Leopoldo G. Mendoza-Espinosa[4], ORCID: https://orcid.org/0000-0002-7795-3665

[1]Independent consultant, Ensenada, Baja California, Mexico, lazaro.elizondo@gmail.com

[2]Instituto de Investigaciones Económicas, Universidad Nacional Autónoma de México, Mexico, aaguilar@iiec.unam.mx

[3]Instituto de Ecología, A. C., Xalapa, Veracruz, Mexico, robert.manson@inecol.mx

[4]Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Ensenada, Baja California, Mexico, lmendoza@uabc.edu.mx

Corresponding author: Leopoldo G. Mendoza-Espinosa, lmendoza@uabc.edu.mx

Abstract

This study presents an assessment of the perceptions and willingness-to-pay (WTP) of farmers using groundwater for irrigation in two aquifers in northern Baja California, Mexico. Contingent Valuation (CV) measured their WTP to ensure availability of groundwater in the future. Data from surveys of 70 and 54 farmers in the Maneadero and Guadalupe valleys, respectively, were combined and analyzed using logistic regression. Farmer WTP is influenced by variables reflecting "present water scarcity for agricultural use", "education and family income levels", "partial use of wastewater for irrigation", "water quality", and "payment amount". A WTP estimate of \$US 0.13/m^3 suggests that the environmental cost of depleting aquifers over a 20-year span could reach \$US 17.4-24.9 million for the Guadalupe aquifer and \$US 20.50 million for the Maneadero aquifer. This information could serve as a starting point to help decision makers in northern Mexico design more environmentally sustainable pricing policies, including investing revenues in long-term aquifer restoration.

Keywords: Aquifer depletion, environmental costs, contingent valuation method, willingness to pay.

Resumen

Este estudio presenta una evaluación sobre las percepciones y la disponibilidad a pagar (DAP) de agricultores empleando agua subterránea para irrigación de productos agrícolas en dos acuíferos del norte de Baja California, México. Se empleó el método de valuación contingente (VC) para medirla y asegurarse de la disponibilidad de agua en el futuro. Se combinaron datos de encuestas de 70 y 54 agricultores de los valles de Maneadero y Guadalupe, respectivamente, analizados usando regresión logística. La DAP de los agricultores es influenciada por las variables "escasez de agua actual para uso agrícola", "nivel de educación", "ingreso familiar", "uso parcial de aguas residuales para irrigación", "calidad del agua" y "cantidad a pagar". Una DAP estimada de \$0.13 dólares/m^3, sugiere un costo ambiental de agotamiento de acuíferos de 17.4-24.9 millones de dólares para el acuífero de Guadalupe y \$20.4 millones para el acuífero de Maneadero. Esta información puede servir como punto de partida para ayudar a tomadores de decisiones en el norte de México a diseñar políticas de precios más sostenibles, e invertir en la restauración de acuíferos a largo plazo.

Palabras clave: agotamiento de acuífero, costos ambientales, método de valuación contingente, disponibilidad a pagar.

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Introduction

The Dublin Statement of 1992 declared water an economic good and highlighted economic valuation as an important tool for improving efficiency and equity in Integrated Water Resource Management (IWRM) plans, particularly within watersheds (Owen, Mirghani, Diene, Tuinhof, & Taylor, 2010). The economic valuation of water resources has subsequently become an important component of groundwater management, helping to both regulate rates of extraction (Koundouri, 2004) and generate royalties or fees for investment in aquifer restoration (Sukhdev, Wittmer, & Miller, 2014; Mancosu, Snyder, Kyriakaki, & Spano, 2015). However, the value of groundwater used for irrigation is rarely quantified (Bierkens, Reinhard, De Bruijn, Veninga, & Wada, 2019), resulting in undervaluation, overexploitation, and poor public management of such resources (Bergkamp & Cross, 2006; Young & Loomis, 2014).

Another reason for valuing environmental assets is increasing awareness of the loss of services that are being poorly managed (Ninan, 2014). This is especially true for groundwater resources that are frequently treated as limitless and low-cost in the agricultural sector (Famiglietti, 2014; Vadiati, Adamowskia, & Beynaghi, 2018). Since irrigation for agriculture accounts for 70 % of groundwater water withdrawals globally (FAO, 2016), and with groundwater depletion increasing by 22 % just in the period 2000-2010 (Dalin, Wada, Kastner, & Puma, 2017), more economic valuation is urgently needed in this sector.

In semiarid and arid regions, indiscriminate groundwater withdrawals can simultaneously worsen long-term water scarcity and water resource management (Siebert *et al*., 2010; Wada, Wisser, & Bierkens, 2014). This is the case in Mexico, where farmers pay nothing for groundwater used for crop irrigation (Garrido & Calatrava, 2010; Tellez-Foster, Dinar, & Rapoport, 2018; Conagua, 2016) and, thanks to notable government subsidies, pay only a fraction of the true electricity costs for pumping groundwater (Muñoz-Piña *et al*., 2006). As a result, groundwater resources in this region are severely undervalued and poorly managed, resulting in elevated rates of groundwater extraction (Badiani & Jessoe, 2013; Suna, Sesmeroa, & Schoengold, 2015). Between 2003 and 2019 increases in overexploitation of groundwater in Mexico resulted in a 7.6 % annual rise in aquifer depletion costs (INEGI, 2020).

This paper aimed to assess the perception of farmers using groundwater for irrigation and their willingness to pay (WTP) for the restoration of aquifers in Ensenada, Baja California, Mexico, a region highly dependent on groundwater for irrigation. We sought to test the hypothesis that valuation of the benefits of providing groundwater for irrigation from the Guadalupe and Maneadero aquifers influences farmer WTP in this region and thus, could help foster improved management of water resources. Apart from the value of water resources as natural capital, users' perceptions of the management of groundwater, electricity subsidies for pumping groundwater for irrigation, and the cost-benefit trade-off of alternative strategies to mitigate water scarcity in the area were also estimated in this study. The socioeconomic and geographic contexts of the study area are presented in the following section, followed by a description of the methodology used for assessing both farmer perceptions and WTP, the presentation of the results obtained, and finally a discussion of our findings and their potential importance in strengthening management recommendations for farmers and decision-makers in northern Mexico.

Regional context

The city of Ensenada and the agriculture-dominated valleys of Guadalupe and Maneadero are located in northwestern Baja California state, Mexico, along the Pacific Ocean (Figure 1). The Guadalupe watershed is predominantly devoted to vineyards, while the Maneadero watershed produces a variety of agricultural products, some of which are exported to the United States. The region has a Mediterranean climate with average monthly temperatures ranging from 12 - 18°C, dry summers, and winter precipitation not exceeding 300 mm (Conagua, 2020). Surface water flow is practically non-existent except during rare storm events with most precipitation either evaporating or infiltrating immediately into the sub-soil and aquifers. According to interviews with the directors of local groundwater technical committees of each aquifer (known by their Spanish acronym COTAS) in 2018, approximately 80 % of the water used for irrigation comes from pumping groundwater (J. Lafarga and A. Guzman, personal communication). COTAS were designed to help regulate groundwater extractions and to stabilize aquifer levels through the decentralization of water resources management and fostering the participation of farmers in decision making (Foster, Garduño, & Kemper, 2004). However, Wester, Sandoval-Minero and Hoogesteger (2011) argue that they have not achieved sustained reductions in groundwater extractions due to substantial subsidies for water and electricity subsidies, as well as a lack of both financial resources and enforcement capability.

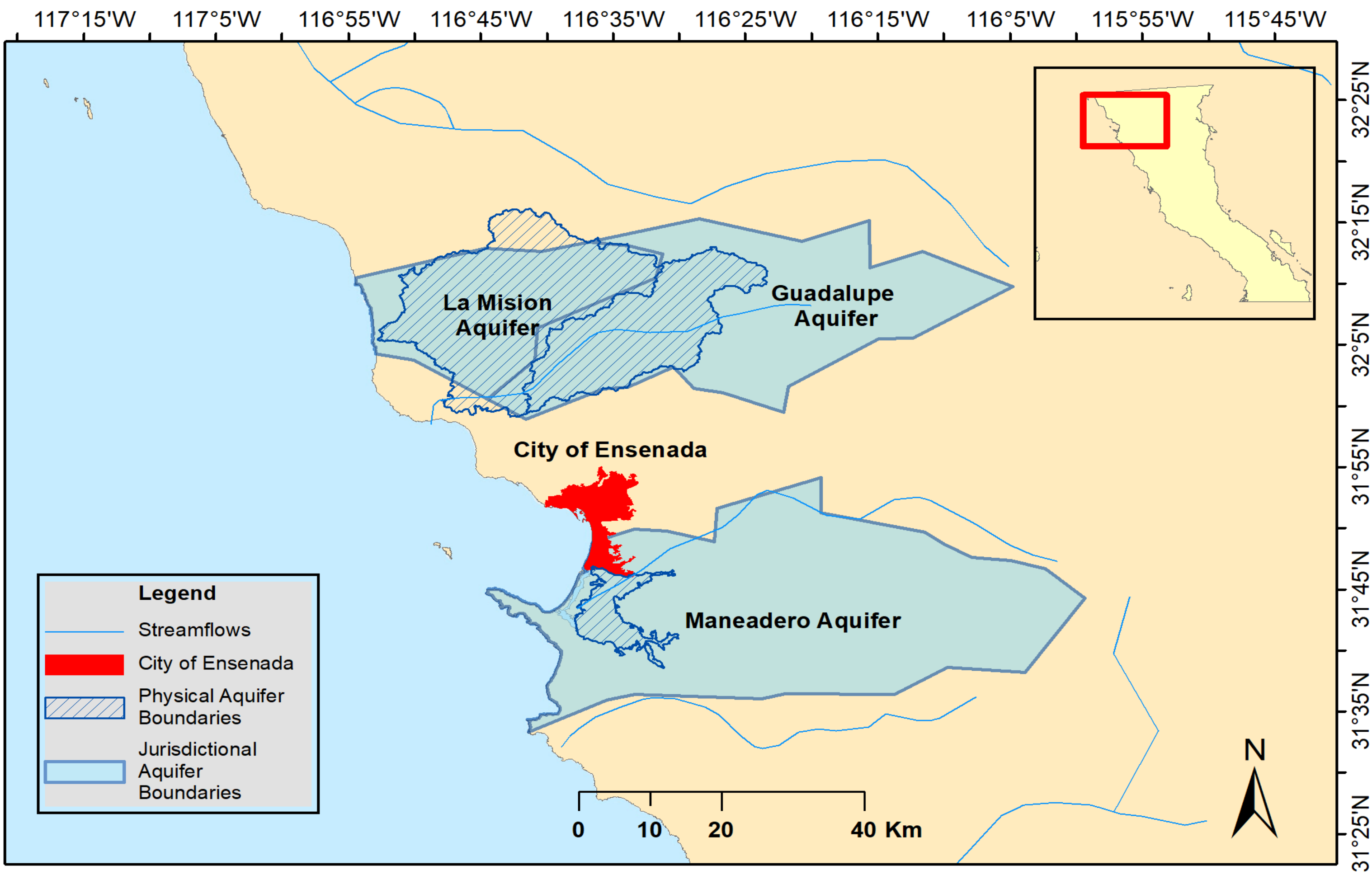

Figure 1. Map of aquifers and water management boundaries in the Guadalupe and Maneadero watersheds in Baja California State, Mexico.

In the Guadalupe valley, there are three small towns, El Porvenir, Las Minas, and Francisco Zarco, with an overall population of 8 611 inhabitants (INEGI, 2020) According to Conagua (2020) annual recharge of the Guadalupe aquifer is approximately 18.8 Mm^3, while average annual extraction is 37.2 Mm^3 resulting in a deficit of -18.4 Mm^3. Approximately 81 % of this water is used for crop irrigation, followed by usage in public water systems (17 %), and for commercial and industrial use (2 %) (REPDA 2018). In 2015 agriculture 2 368 ha were used for agriculture, 81.9 % (1940 ha) for vineyards and 18.1 % (428 ha) for crops like olives, oranges, lime and alfalfa. Grape production from the Guadalupe valley in 2017 was for wine (17 283 tons) and fruit (3 386 tons), with a commercial value exceeding $19.9 million USD (Sagarpa & Sefoa, 2017).

The Maneadero valley, located 10 km south of the city of Ensenada, has a population of approximately 30 656 inhabitants (OIEDRUS 2015). According to Conagua (2018), annual Maneadero aquifer recharge is 33.8 Mm^3, with extraction totaling 38.5 Mm^3 and a resulting annual deficit of -4.7 Mm^3. The Maneadero aquifer supplies 15.3 % (190 lps or 5.9 Mm^3) of the annual water budget for the city of Ensenada for general use (CESPE, 2017). According to OIEDRUS (2015), in 2015 the total agriculture surface was 3756 ha. Investment in the partial (150 lps) reuse of treated wastewater from Ensenada in this valley for irrigation of 400 ha and the production of fodder, flowers, and wood products in three harvest cycles is estimated to generate USD $14.2 million and provide 4 000 jobs annually (Villareal, 2021).

Methodology

Willingness to pay

In the present study, farmer Willingness to Pay (WTP) to preserve groundwater for irrigation in both Guadalupe and Maneadero valleys was calculated using contingent valuation (CV). CV has been used to measure the value of non-market goods and seeks to elicit individuals' preferences in monetary terms in a variety of contexts (Bateman *et al*., 2013; Young & Loomis, 2014). Economic value is assessed using a hypothetical scenario whereby a sample of the population is interviewed, and individuals are asked to state their WTP for an increase or decrease in quantity or quality of a given environmental good or service (Hanemann, 2006).

The survey

A CV survey was designed (see supplementary material) following procedures in Carson and Hanemann (2005), and Salman and Al-Karablieh (2004) and consisted of four sections:

1. Background for respondents, providing a detailed description of the water supply of each aquifer, and the costs of water per m^3.
2. Assessment of the perceptions of farmers, including their attitudes towards water resources and the environment, and their degree of confidence in water management institutions, using a Likert scale.

3. Presentation of a hypothetical scenario with an associated WTP value scale allowing respondents to select among amounts and forms of payment, and to justify unwillingness to pay if that was the case.

4. Questions describing the socio-economic profile of survey respondents.

To determine the appropriate survey sample size (n) for each watershed, the following formula was used:

$$n = N/1 + Ne^2$$

Where:

N = farmer population.

e = level of precision assuming a 95 % confidence level and 5 % margin of error.

Farmers in each watershed were randomly selected using systematic selection (K): K = N/n (Hernández-Sampieri, Fernández-Collado, & Baptista-Lucio, 2006) and associated lists of farmers from COTAS and the Public Register of Water Rights (REPDA). Questionnaires were applied from May to October 2016. Guadalupe's substantially larger number of farms (and water concessions) made sampling more challenging and resulted in a lower proportion of farms surveyed overall: a total of 153 and 158 questionnaires, representing 47 and 29 % of total agriculture concessions in Maneadero and Guadalupe watersheds, respectively. Prior to the application of the survey, a pilot test was conducted with 15 farmers in both watersheds to verify that responders understood the questions and had time to respond to them and to receive additional feedback from respondents for improving this instrument. As with the overall survey, individuals for the pilot test were selected randomly from the list of farmers registered in COTAS.

A complete description of the independent variables from the survey considered in the WTP analyses is presented in Table 1.

Table 1. List of independent and dependent (*) variables included in contingent valuation (CV) analyses of changes in willingness to pay (WTP) by farmers using groundwater for irrigation in the Guadalupe and Maneadero watersheds in Baja California, Mexico. Each variable was assigned a unique code and is briefly described together with the type of measurement unit, type of variable, and potential relationship with the payment amount (Sign).

Variable Code	Variable Description	Measurement Units	Variable Type	Sign
RGEN	Respondent's gender	1=female, 0=male	Nominal	–
RAGE	Respondent age	Likert scale	Ordinal	–
HEDU	Highest education level	Likert scale	Ordinal	–
TFIN	Total family income	Mexican Pesos	Ordinal	+
GWVA	Perception of groundwater value as a natural resource, a non-valued human right, or a private right	Likert scale	Ordinal	+
OVEX	Perception that over extraction has caused aquifer depletion	Likert scale	Ordinal	+

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Variable Code	Variable Description	Measurement Units	Variable Type	Sign
WREX	Willingness to reduce extraction today to maintain future availability	Likert scale	Ordinal	_
WCST	Farmer water concession status	Likert scale	Nominal	+
WAQU	Perception of the importance of water quality for agricultural irrigation	Likert scale	Ordinal	_
LOST	Land ownership status by the concessionaire	Likert scale	Nominal	_
OIMA	Perception that aquifer is overexploited due to inefficient management	Likert scale	Ordinal	_
OLEV	Perception that aquifer is overexploited due to lack of economic valuation	Likert scale	Ordinal	+
AIWS	Perception that agriculture intensification is causing current water scarcity	Likert scale	Ordinal	_
DWMA	Perception of deficient water management by the Ensenada State Commission of Public Services (CESPE)	Likert scale	Scale	+
GCOA	Perception that groundwater concessions are overallocated	Likert scale	Scale	+
AQOE	Perception of aquifer overexploitation	Likert scale	Scale	+
ITWI	Perception of insufficient use of treated wastewater for irrigation	Likert scale	Scale	+
ISHI	Perception that decision makers ignore stakeholder input	Likert scale	Scale	_

Variable Code	Variable Description	Measurement Units	Variable Type	Sign
PMSG	Farmer preferred maximum for the supply of groundwater for irrigation estimated per cubic meter	Mexican Pesos, Likert scale	Scale	_
WTP*	Willingness to pay to ensure the supply of water for irrigation per cubic meter based on stated costs	Likert scale Yes=1, No=0	Nominal	

Of the 311 questionnaires sent to farmers in both valleys, 124 were completely answered and returned, resulting in a response rate of 39.8 %. Response rates for Maneadero (70 questionnaires returned, 45.7 %) were higher than for the Guadalupe watershed (54 questionnaires returned, 34.1 %). Surveys from both watersheds were combined in our analysis resulting in a single WTP value for farmers in the study region.

The model

For data codification, econometric analysis, estimation of WTP, and the evaluation of variables that could influence WTP, a binary logistic regression model was used in SPSS® v23. Respondents were presented with a set of alternatives and revealed their preferences by the choices that they made in the survey (Greene, 2012). This type of modelling has proven useful for estimating the WTP of farmers for irrigation groundwater in previous studies (Storm, Heckelei, & Heidecke, 2011; Shantha and Asan-Ali, 2014). The valuation function was statistically related to participants' WTP with a set of explanatory variables. A respondent's WTP reflects a threshold (yes or no) of their willingness to pay to obtain a good or service. The attributes of a good or service and the socioeconomic characteristics of the participants are usually used as covariates in this type of analysis (Kriström, 1990; Riera *et al*., 2012). Logistic regression models estimated the parameters of the relationship between the dependent and independent variables and predicted the dependent variable from a set of covariates (Hosmer, Lemeshow, & Sturdivant, 2013). In these models the dependent variable WTP is binary and coded as "0" if there is no willingness to pay and as "1" if there is willingness to pay under a given scenario. The model equation is exponential and, with logarithmic transformation can be presented as the function (Kleinbaum & Klein, 2010):

$$ln\left(\frac{\hat{y}}{1-\hat{y}}\right) = \beta_0 + \beta_i x_i + \epsilon \qquad (1)$$

Where:

y = Willingness To Pay

x_i = Independent variables

β_0 = Constant term

β_i = Regression coefficient of variable i

ϵ = Error term

Farmer's mean maximum WTP was calculated by dividing the coefficient of the constant by the coefficient of payment (Kriström 1990; Riera *et al*., 2012). WTP was also used to estimate the value of groundwater as a natural capital by multiplying WTP by the quantity (m^3)

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of water lost due to overexploitation or the quantity of water required to restore or recharge aquifers.

The independent variables were grouped into categories of exploratory variables and ranked according to missing observations (lack of response in the survey). Variables that had two or more missing observations were eliminated to improve model quality. Additionally, independent variables were tested for correlations before logistic regression analysis with only one of a pair of correlated variables used in model construction.

Results

Socio-economic characteristics of the surveyed population

A total of 81.5 % of survey respondents were male (57 in Maneadero, 44 in Guadalupe) and only 18.5 % were female (13 Maneadero, 10 Guadalupe). Farmers' average age was 52. Most families were composed of four members. In terms of education, 8 % of respondents had completed postgraduate studies, while 29 % had completed a university degree, 3 % technical studies, 27 % high school, 22 % secondary, and 10 % primary studies with only 1 % having no formal education. The average income of participants in the survey was USD $966 per month, which is 42 % higher than per capita income nationally in Mexico (USD $680; INEGI, 2017) using 2017 prices.

Assessment of farmer perceptions

The majority of farmers (61 %) perceived groundwater from aquifers as a natural resource of great value for ensuring future water supply; 21 % recognized this water as a public resource that must be valued, and 16 % regarded it as a human right that has not been valued. Most respondents (87 %) agreed that excessive extraction of groundwater has led to aquifer overexploitation. Likewise, 81 % agreed that this overexploitation has resulted from a lack of economic valuation and indicated (87 %) they were willing to reduce water extraction rate now to ensure greater availability in the future. Regarding water irrigation methods, 87 % of farmers use drip irrigation, 6 % sprinklers, and 3 % open channels to transport water in the study watersheds.

Slightly less than half of farmers (48 %) were unsure about transparency in water management by the institutions in charge (municipal, state, and federal), while 13 % concluded that there is no transparency and 39 % characterized water management as transparent. The majority of farmers (74 %) believe that aquifers have been overexploited due to poor management by the responsible local, state and federal institutions like CESPE, the Baja California Water Commission (CEA) and Conagua, versus 8 % that thought this was not the case and 18 % that did not express an opinion. Additionally, the lack of enforcement of environmental laws was recognized by 77 % of farmers as another cause of water mismanagement in the area. Regarding perceptions of representation in dialogues with municipal, state, and federal agencies on water issues, only 38 % of respondents felt adequately represented, while 45 % were not sure, and 16 % did not feel represented at all. Most respondents (92 %) felt that politicians do not take into account proposals by scientists, farmers, and NGOs to improve aquifer management, which include the use of reclaimed water for crop irrigation and aquifer recharge.

Only 28 % of those surveyed have confidence in the way the federal agency Conagua is managing groundwater, while 36 % are uncertain, and 35 % have no confidence in Conagua's management. In contrast, 58 % concur that COTAS have contributed to improved groundwater management, with 30 % of respondents being undecided. Interestingly, those with agricultural concessions perceive (66.9 %) that COTAS do not have the authority, nor the human and financial resources, to manage groundwater adequately. A clear majority of farmers (76 %) identify planting crops with less water demand and greater profitability as a potential measure for improving groundwater management. A majority also consider current water scarcity for irrigation a serious matter (62 %), with 77 % indicating that the situation will be very serious in 10 years.

When asked about possible immediate solutions to reduce aquifers' overexploitation, 79 % of farmers viewed the application of treated wastewater as a viable option for irrigation if tertiary treatment is added. Likewise, 76 % considered the idea of injecting treated wastewater into aquifers to replenish them a promising alternative and 81 % perceived reducing electricity subsidies for pumping out groundwater for irrigation as a non-urgent solution.

Variables influencing WTP

The results of the stepwise logistic regression model with the variables that best explain WTP of farmers for conserving groundwater are summarized in Table 2. Results of the goodness-of-fit tests of the logistic regression model (Omnibus $\chi^2_6 = 20.850$, $p = 0.002$) with six independent variables indicated a rejection of the null hypothesis and that the several independent variables had a significant influence on the response variable WTP. Overall, the model successfully predicted farmer WTP with 97.6 % accuracy. Therefore, the hypothesis that the valuation of the benefits of groundwater for irrigation from the aquifers' Guadalupe and Maneadero helps explain farmer's WTP is supported. The independent variables included in the model explained about 21.8 and 69 % of the variation in dependent variable WTP according to Cox and Snell and Nagelkerke R^2 values, respectively. Results from the Wald tests for each of the independent variables in the model indicate that the variables that best explain WTP are AIWS and HEDU, followed by TFIN, ITWI, WAQU and PMSG. As the perception that agriculture intensification is causing water scarcity (AIWS), the importance of water quality for irrigation (WAQU), the highest education level (HEDU), and the preferred maximum for the supply of groundwater for irrigation (PMSG) increased, WTP to restore aquifers with treated sewage water decreased. In contrast, as total family income (TFIN) and the perception of underutilization of wastewater for irrigation (ITWI) increased, WTP also increased.

Table 2. Summary of the variables identified as significant in a logistic regression model in explaining farmer WTP for groundwater conservation in Baja California, Mexico.

Variable	B	Standard Error	Wald χ^2	Sig	Exp(B)	95 % C.I. for EXP(B)	
						Lower	Upper
Constant	-39.536	3827.863	0.000	0.992	0.000		
HEDU	0.909	0.534	2.896	0.089	2.483	0.871	7.078
TFIN	3.257	2.093	2.421	0.120	25.973	0.429	1571.282
PMSG	16.671	3827.842	0.000	0.997	17382330.33	0.000	-
ITWI	1.645	1.171	1.972	0.160	5.179	0.522	51.424
AIWS	5.241	2.733	3.676	0.055	188.775	0.890	40048.1011
WAQU	1.187	1.028	1.334	0.248	3.278	0.437	24.582

Environmental cost of aquifer depletion

The estimated farmer WTP was $US 0.13, which can be interpreted as the average amount that sampled farmers with agricultural concessions would be willing to pay per m^3 of water extracted/utilized to ensure the continued benefits of provisioning groundwater for irrigation from the aquifers in the study watersheds. To obtain a value of the environmental cost of the depletion of the study aquifers, estimated WTP was multiplied by the quantity of m^3 lost over a 20-year span. Historic (1996) values of water availability for the Guadalupe aquifer from Conagua (1998) and Andrade-Borbolla (1997) were used for these calculations and estimated as 218 Mm^3 and 160 Mm^3, respectively. Conagua (2020) reported a water availability of 26.4 Mm^3 in 2016 for the same aquifer, suggesting a loss over 20 years of between 133.6 to 191.6 Mm^3 or 84-88 % of water reserves. In monetary terms, this is equivalent to $US 17.4-24.9 million since 1997 (at current prices). This figure represents the environmental cost of aquifer depletion for the period 1997-2016 or approximately $US 1 million per year. Likewise, the Maneadero aquifer had an availability of 419.8 Mm^3 in 1997 that declined to 262.1 Mm^3 in 2016 (Conagua, 2003; Conagua, 2018), representing a depletion of about 157.7 Mm^3 (38 %) in 20 years. The estimated environmental cost of the overexploitation of this aquifer is $US 20.50 million during the period 1997-2016 (current prices), which is similar to the annual figure for the Guadalupe aquifer of an approximate cost of $US 1 million per year.

Discussion

The estimate of the value of a cubic meter of water in this study ($US 0.13/ m^3) is similar to that of other studies. Medellin-Azuara, Mendoza-Espinosa, Lund, Harou and Howitt (2009) used the CALVIN Hydro-economic model to estimate shadow values for irrigation water for Guadalupe and Maneadero aquifers of $US 0.07 /$m^3$ and $US 0.12 /$m^3$, respectively at 2017 prices. Vélez-Rodríguez, Padilla-Bernal and Mojarro-Dávila (2015) estimated the value of water between $US 0.11 /$m^3$ and $US 0.12 /$m^3$ for agricultural use by producers in two aquifers of Zacatecas State, Mexico. In other arid or semi-arid regions of the world, the value of a cubic meter of aquifer water also approximates these figures. Bozorg-Haddad, Marzieh-Malmir, Mohammad-Azari and Loáiciga (2016), applying a probabilistic optimization method in the coastal region of Khazar in Iran, found that farmers' WTP was $US 0.17 /$m^3$ at 2017

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prices. Storm *et al*. (2011), using contingent valuation and a logistic regression model in the Moroccan Drâa Valley estimated average WTP by farmers for groundwater for agricultural use was between $US 0.09 and 0.18 /$m^3$ at 2017 prices. Wei *et al*. (2007) in northern China, estimated that farmers' WTP is $US 0.19 /$m^3$. Overall, the WTP value for irrigation water in these arid or semi-arid regions appears to be remarkably similar, despite possible variation in water scarcity, culture, and socioeconomic conditions.

Contingent valuation has been widely used for more than 25 years as a versatile and powerful methodology for estimating the monetary value of non-market goods (Carson, 2012; Tang, Nan, & Liu, 2013). However, WTP should not be understood in the same terms in which transactions are made in the market. This is a form of psychological equivalence that implies the improvement of a resource for individual well-being. Rather, WTP is a measure of satisfaction that describes a willingness to sacrifice income in the short-term to ensure the long-term conservation of ecosystems and the services they provide (Kareiva, Tallis, Ricketts, Daily, & Polasky, 2011). WTP is a measurable value that represents the particular choices, interests, incomes, education, and perceptions of stakeholders, and provides information about the value that people assign to different alternatives and thus can be a valuable guide to solve the conflict of the use of resources by allowing stakeholders to measure the impact of their choices on a monetary scale (Kriström, 1990).

One possible methodological limitation of our study was the lack of separate estimates for each aquifer. We were forced to pool our data into a single analysis due to a reduced sample size, however, dummy variables used in the logistic regression analysis (*i.e.*, 1 = Guadalupe; 0 = Maneadero; Hosmer *et al*., 2013) revealed this was not a problem since no statistically significant differences were detected between watersheds. This result should not be surprising since both valleys exhibit similar degrees of water scarcity, a dependency on groundwater as the only source of water for irrigation, subsidies for the cost of groundwater and electricity for extracting groundwater for irrigation, use of technology (drip irrigation predominates), and decision-making structures with each valley having its own COTAS regulated by Mexico's National Water Law under Conagua.

The estimated economic value of aquifer depletion of approximately $US 1 million yr^{-1} for both aquifers in this study should help inform public policy in Baja California, Mexico. On the one hand, this figure can be interpreted as the opportunity cost for using groundwater in the future assuming current rates of extraction and levels of scarcity remain constant (Job, 2010). In other words, this is the amount of water that future generations will not have access to without additional efforts to reduce consumption or by restoring supply. On the other hand, saving water for future uses would also imply an opportunity cost. In fact, in the short term, lower levels of agricultural production would be potentially observed in comparison to current levels of production. In the mid-and long-term, however, a constant supply of water for future irrigation would be assured, bringing in benefits for future generations. Under the sustainable development principles, the latter scenario should be preferred. It is noteworthy to mention that under both scenarios, subsidies directed to lower water extraction costs (either in the form of

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lower electricity, water tariffs, or both) to producers remain an unsustainable practice that hampers conservation efforts. Indeed, sustainability implies a trade-off between present and future generations in the use of resources that becomes very apparent through these types of calculations. Not surprisingly, 81 % of the farmers perceived reducing electricity subsidies for pumping out groundwater for irrigation as a non-urgent solution. The subsidy of 91.6 % in electricity that the farmers received in 2015 represented a total of 1 337 million pesos (equivalent to USD $70.4 million) (Sagarpa, 2016) so there is little incentive to change this.

The current levels of aquifer depletion in the Guadalupe and Maneadero aquifers highlight the fact that groundwater use is currently unsustainable. One way to overcome this challenge would be to require the federal government to reconsider its subsidies for water pumping. Not surprisingly, most of the regions in Mexico where aquifers are overexploited correspond to those with higher electricity subsidies for agricultural irrigation (Robles-Berlanga, 2017). These subsidies create perverse incentives to over-exploit groundwater resources (Badiani & Jessoe, 2013; Tellez-Foster *et al*., 2018; Suna *et al*., 2015). According to the Centro Mario Molina (2014), government spending for this type of subsidy to the agricultural sector increased 157 % between 2003 and 2013. Furthermore, Robles-Berlanga (2017) points out that such a subsidy is particularly regressive because it benefits the richest farmers the most. The OECD (2015) has already recommended that Mexico eliminate electricity subsidies for irrigation pumping that have detrimental impacts on water demand as well as groundwater management. However, current political and social realities in the country make this a very difficult decision. Tellez-Foster *et al*. (2018) and Muñoz-Piña *et al*. (2006), propose decoupling as an alternative policy intervention to circumvent these issues. Decoupling is the process whereby the economic value of the current subsidy is converted into a direct economic transfer or additional income for farmers who are then charged the real electricity prices that will increase over time as the water table drops and more energy is required for pumping (Muñoz-Piña *et al*., 2006).

Alternatively, our estimates of aquifer depletion costs may serve as a benchmark for investing in Aquifer Storage and Recovery (ASR) technologies (Barber 2007). In both the Guadalupe and Maneadero watersheds, alternatives include using treated wastewater for irrigation and treated wastewater for recharge of depleted aquifers (Elizondo & Mendoza-Espinosa 2020). Indeed, Abdalla and Al-Rawahi (2013) suggest that measures to reduce extraction can be more effective when combined with the restoration of aquifer levels by using this type of technological innovation.

Conclusions

Contingent Valuation was used to measure farmer WTP to ensure the continued use of groundwater for irrigation in two arid valleys in northern Mexico. Results indicate that WTP is significantly influenced by variables such as present water scarcity for agricultural use, education level, family income, the partial use of treated wastewater for irrigation, water quality for irrigation, and WTP amount. The WTP estimate of $US 0.13 /m^3 obtained in this study is consistent with many other studies conducted in arid or semi-arid regions and suggests that the environmental cost of depleting aquifers over a 20-years span could range between $US 17.4-24.9 million for the Guadalupe aquifer and $US 20.50 million for the Maneadero aquifer. This information, including the high economic costs of doing nothing, and the willingness of local farmers to help pay for possible solutions, could serve as a starting point for decision-makers faced with the challenge of designing an environmental pricing policy that values groundwater for irrigation according to farmers WTP and invests potential revenues in strategies that ensure the long-term restoration and conservation of aquifers. Both decoupling of electricity subsidies for pumping groundwater and complementary use of treated wastewater for irrigation and aquifer recharge after adding tertiary treatment and quality control should be considered as viable tools in the development of future strategies in this region.

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