Determining the value of environmental goods that impact human populations, such as potable water, is often highly problematic. The all-too-common lack of realistic markets for the provisioning of these goods necessitates the use of nonmarket valuation techniques. Contingent valuation surveys are often an appropriate method, thanks to their ability to value hypothetical changes and nonuse values, and their limited prior data requirements. When properly implemented, contingent valuation surveys can estimate the maximum willingness to pay of surveyed individuals, allowing the value of the environmental good to be accurately measured. An analysis of the extant body of contingent valuation studies of rural potable water systems in developing and emerging countries indicates that rural water consumers are willing to pay, often substantially, for the creation of a potable water system or for improvements to existing system. Studies involving changes to existing potable water system, through improving an existing system for greater reliability or sustainability, showed a high degree of consistency in respondents’ willingness to pay estimates as a percentage of income or current water tariff. Higher incomes, higher levels of education and youth, among other characteristics, were found to be positively correlated with higher willingness to pay estimates. Future contingent valuation studies focusing on improving comparability through greater methodological consistency, and addressing the impact of community power dynamics, intercommunal cleavages, and subsidies could be especially productive.

This article is categorized under:
Human Water > Value of Water
Engineering Water > Planning Water
Human Water > Water Governance

KEYWORDS
contingent valuation, nonmarket valuation, potable water, sustainable development, willingness to pay

1 INTRODUCTION

Climate change, urbanization, and economic growth place increasing stress on water resources, particularly in emerging and developing countries. Lack of access to potable water in rural areas remains one of the greatest global challenges in development (Alcamo, Flörke, & Märker, 2007; Arnell, 1999; Schlosser et al., 2014; Vörösmarty, Green, Salisbury, & Lammers, 2000; Wada, Van Beek, & Bierkens, 2011). However, with limited resources at hand, policy-makers must choose between a variety of development priorities, including not only the provision of potable water, but healthcare, education, nutritional needs and economic growth.

To accurately analyze the costs and benefits of competing policy options, it is necessary to understand their relative value to the individuals impacted by them (Carson, Flores, & Meade, 2001; Whittington, 1998). However, it is challenging to
determine this value because many environmental goods, including potable water, are not priced on an open market (Alfnes & Rickertsen, 2011; Costanza et al., 1997; Smith, 1993). Such a market may not exist, or it may be flawed and therefore fail to reflect actual value.

Economists employ a variety of methods to define value in situations like this. These methods are referred to collectively as nonmarket valuation. One of the most popular nonmarket valuation techniques is the contingent valuation method (CVM). Contingent valuation involves surveying individuals using a hypothetical market to determine respondents’ willingness to pay (WTP) for the provisioning of a particular environmental good (Ardila, Quiroga, & Vaughan, 1998; Boyle, 2003; Carson, 2012).

Contingent valuation surveys have been increasingly used to estimate the value of environmental goods in studies conducted around the world (Alberini & Cooper, 2000; Loomis, 1997; Venkatachalam, 2003). Given the topical breadth of these studies however, this paper narrowly focuses on studies of potable water systems in rural areas of developing and emerging economies. Potable water system will be used throughout this paper to describe any system designed to supply consumers with safe water for drinking and other household uses. This excludes systems designed to supply irrigation water, except as a byproduct of a system primarily structured around residential usage. This targeted approach allows a focus on the unique challenges faced at the intersection of water policy, public health, and sustainable rural development goals. The studies examined here include those that measure willingness to pay for the creation of a potable water system, those measuring willingness to pay for the improvement of an existing potable water system to provide greater reliability, and, finally, those measuring willingness to pay for the improvement of an existing potable water system to achieve an environmental benefit not directly related to the welfare of water consumers. The inclusion of these last studies allows an interesting comparison of respondents’ willingness to pay for an increase in the use versus nonuse benefits derived from water goods.

While urban areas of developing and emerging countries also face water challenges, these problems are often of a different scale and nature. Worldwide, 85% of urban inhabitants have regular access to potable drinking water, compared to only 55% of the world’s rural population. In developing urban areas, the most pressing water challenges generally involve the disposal of wastewater and provision of sanitation services, rather than potable water supply (Van Rooijen, Biggs, Smout, & Drechsel, 2009). For instance, in Cameroon, 88% of the urban population has access to potable drinking water, compared to only 47% of the rural population. However, access to sanitation facilities shows much greater parity, with 58% of urban residents and 42% of rural residents having access to reliable sanitation (Ako, Shimada, Eyong, & Fantong, 2010). Given these divergent challenges, this paper will focus exclusively on rural water systems providing potable drinking water.

This paper builds off of other review and analysis work on stated preference studies of rural water resources, such as Van Houtven, Pattanayak, Usmani, and Yang (2017). However, this paper contributes a unique focus to the review literature on the subject, introducing nonspecialists to the contingent valuation process, providing an in-depth review of existing contingent valuation studies, analyzing how the specific choices of methodology and context, as well as demographic variables, impacted willingness to pay estimates, and providing possible fruitful avenues of future research.

2 | NONMARKET VALUATION

Attempting to assign monetary value to environmental goods, such as clean air or water, is a challenging endeavor, since these goods lack the exchange market present for other goods, such as clothing or housing (Costanza et al., 1997; Smith, 1996). Should a government invest in providing a new drinking water system, or increase the funding available for elementary schooling? Conversely, should a protected area be opened for mining, providing local jobs and tax revenue, or do the environmental costs outweigh the potential benefits? How should limited water supplies be allocated between residential, industrial, and agricultural uses? Without reasonable estimates of the value of the goods in question, evaluating the costs and benefits of these tradeoffs is impossible. In the absence of market pricing to provide these values, economists have developed a variety of methods to estimate them, and thus reflect the relative importance that individuals place on them.

Value, as used by economists, is the relative desirability of one good or amenity compared to others, as expressed in monetary terms. Environmental goods are different than many other goods, in that a large component of their value extends beyond that derived from their direct use, and any form of valuation must consider these nonuse values as well (Alfnes & Chavas, 1985).

Nonuse values describe benefits not directly consumed by the individual. An example of this would be altruistic value, the benefit derived from a knowledge that others are benefiting from a good. A good’s total economic value (TEV) is the sum of its use and nonuse values; when economists seek to determine the value of a good for cost–benefit purposes, they must ensure that the totality of its value is being assessed (Bateman & Turner, 1992; Loomis, 2000; Mitchell & Carson, 1989).

Nonmarket valuation (NMV) becomes necessary when the total economic value of a particular good is not adequately expressed in its market price (Bateman & Turner, 1992; Boyle & Bishop, 1988; Mitchell & Carson, 1989). This occurs with some environmental goods, like clean air, because they are simply not traded in markets and thus have an effective price of...
zero. For other goods, there may be some market price provided for the good, but many individuals would be willing to pay more than the current market price, such as is the case in many places for quality water supply (Alberini & Cooper, 2000; Loomis, 2000; Venkatachalam, 2003).

3 | THE CONTINGENT VALUATION METHOD

The contingent valuation method (CVM) is a nonmarket valuation method which asks individuals to state the maximum that they would be willing to pay (WTP), and are able to pay, for a particular quantity or quality of an environmental good (Ardila et al., 1998; Bateman & Turner, 1992; Boyle, 2003; Boyle & Bishop, 1988; Carson, 1985; Carson, 2012; Hanemann, 1994; Mitchell & Carson, 1989). Less frequently, an individual might be asked how much they would be willingness to accept (WTA), as a minimum, in compensation for the loss of an environmental good. Contingent valuation is a stated preference form of nonmarket valuation, as the estimate of an individual's willingness to pay is derived from their responses to a hypothetical scenario. An individual might be asked directly how much they would be willing to pay for a specified quantity of an environmental good, or asked whether they would be willing (and able) to pay a specified amount. Once the individual estimates, or bids, have been obtained, they can be averaged and aggregated, providing an overall value for the good in question. Additionally, contingent valuation surveys generally calculate how willingness to pay estimates are impacted by demographic variables such as income, age, and education (Boyle, 2003; Carson, 2012; Loomis, 2000). Contingent valuation is particularly capable of evaluating a hypothetical change in an environmental good and can express the full range of a good's total economic value. However, it is predicated on the assumption that the individuals being surveyed are accurately (and honestly) capable of expressing how much they are willing to pay for the good in question (Boyle, 2003; Carson, 2012; Hanemann, 1994; Loomis, 2000).

3.1 | The contingent valuation process

While contingent valuation surveys can be used to value an almost unlimited variety of goods in a range of settings, contingent valuation surveys follow a relatively consistent process. The steps of the basic contingent valuation survey process are shown in Figure 1.

In order to conduct a contingent valuation survey, the bounds of the study must be set, determining exactly what good is being valued, by whom, and over what time period and area (Bateman & Turner, 1992; Hanemann, 1994; Loomis, 2000; Mitchell & Carson, 1989). This allows for a meaningful scenario to be constructed and presented to the survey respondents. For instance, a study might seek to measure the willingness of smallholders in a particular river catchment area to pay for an improvement in the quality of drinking water over the next 2 years.

Next, a hypothetical market needs to be constructed, clearly outlining the precise good being provided (in quantity and quality), the method (known as the bid vehicle) by which the respondents would hypothetically pay for this good, and the means by which the good would hypothetically be provided (Bateman & Turner, 1992; Hanemann, 1994; Loomis, 2000; Mitchell & Carson, 1989). Following the previous example, the survey might aim to estimate "How much would you be willing to pay, per month in user fees, for a community-owned water provisioning system that would provide potable drinking water?" Here, the good being provided is potable drinking water, the bid vehicle is monthly user fees, and the means of provision is a community-owned water system. Outlining all of these characteristics precisely allows the respondents to more accurately estimate their willingness to pay.

The surveyor must determine the bidding mechanism to be used in the survey. The bidding mechanism is the means by which the survey respondents express their willingness to pay estimates (Bateman & Turner, 1992; Hanemann, 1994; Loomis, 2000; Mitchell & Carson, 1989). This may take the form of an open-ended question, where respondents state directly their maximum willingness to pay. More commonly, respondents might be asked whether or not they would be willing to pay a specified price for a quantity of the good, a bidding mechanism known as dichotomous choice elicitation, or referendum elicitation. A variant of dichotomous choice is the bidding game, where respondents are offered an escalating series of bid prices, and indicate their willingness to pay each price successively, stopping when they reach a price they would be unwilling to pay. Dichotomous choice elicitation provides a closer approximation of actual consumer decision-making, and thus is generally considered to provide more valid willingness to pay estimate; however, it requires more extensive pilot testing to accurately establish the range of prices to be offered and requires large samples of respondents, so a range of bid prices can be offered (Carson et al., 2001; Johnston et al., 2017).

After the hypothetical market has been designed and bidding mechanism chosen, the actual survey questionnaire, or instrument, can be drawn up. A well-designed questionnaire provides an introduction explaining the context of the survey, a clear description of the hypothetical market, and a series of questions obtaining information on demographic variables which might
impact willingness to pay estimates, in addition to the actual bidding mechanism (Arrow et al., 1993; Carson, 2012; Carson et al., 2001; Loomis, 2000; Whittington, 1998).

An essential, but unfortunately sometimes overlooked, step is to conduct a pilot survey, a smaller survey testing out the effectiveness of the hypothetical market, bidding mechanism, and questionnaire design. This allows any problematic components of the survey design to be amended before the full survey is conducted (Arrow et al., 1993; Bateman & Turner, 1992; Carson, 2012; Carson et al., 2001; Whittington, 1998). For instance, if respondents begin to drop out of the survey during a lengthy bidding game, the surveyor can change to an alternative mechanism instead.

Once the surveys are completed, the average willingness to pay bids can be calculated. The collection of demographic, attitudinal, and other potentially impactful data allows a bid curve to be estimated. The bid curve shows maximum willingness to pay as a function of the effect of these factors, when combined with individual variance. Using regression analysis, a best-fit bid curve can be created. Finally, the maximum willingness to pay can be aggregated to the population of the impacted area as a whole, allowing the overall value of the target environmental good to be calculated (Bateman & Turner, 1992; Carson et al., 2001; Hanemann, 1994; Loomis, 2000).

Contingent valuation surveys have the potential to estimate values for goods which would otherwise be prohibitively challenging. Analysis of the results from contingent valuation studies show that, when conducted properly, they reflect results that are consistent with basic economic principles and in accordance with actual referendum or initiative voting on related topics.
When compared against other nonmarket valuation methods, the results from contingent valuation studies have generally held up to scrutiny (Carson, 2012; Carson et al., 2001; Loomis, 2000). However, while this evidence supports the conclusion that contingent valuation surveys are capable of providing valid and reliable valuations for environmental goods, it also highlights the importance of conducting studies with the greatest possible attention to best practice (Arrow et al., 1993; Boyle, 2003; Carson, 2012; Carson et al., 2001; Johnston et al., 2017; Loomis, 2000; Memon & Matsuoka, 2002; Whittington, 1998).

4 | THE PAST: CONTINGENT VALUATION STUDIES AND RURAL WATER USERS TO DATE

In order to provide a systematic overview of the extant contingent valuation studies of rural potable water systems, the current body of published literature was examined. An effort was made to find every English-language contingent valuation study addressing rural potable water systems subjected to a process of peer-review. This necessarily entailed excluding non-English language studies or those, such as dissertations or working papers, which have not gone through the peer review process. The potential pool of studies was limited to those studies that were conducted predominantly or exclusively in a rural or peri-urban setting, within countries defined by the International Monetary Fund (IMF) as Emerging or Developing Economies. This was considered necessary to separate out the much more numerous contingent valuation studies conducted in a very different high-income or highly urbanized context.

A total of 52 peer-reviewed papers were found during this search. However, 19 of the papers were not included in this analysis because they failed to meet minimal standards of contingent valuation best practice. Given the efforts of environmental economists to establish the validity of stated preference valuation, this should be cause for some concern among those seeking to promote the greater use of contingent valuation studies in the context of rural water usage.

Based on best-practice criteria outlined by Arrow et al. (1993), Whittington (1998), Loomis (2000), Carson et al. (2001), White, Jennings, Renwick, and Barker (2005), Carson (2012), Riera et al. (2012), and Johnston et al. (2017), the 52 studies found through the search process were evaluated for their adherence to the following best practices: clearly described hypothetical market (with clear and credible descriptions of the water good being valued, method of payment, and means of provision), justification of bidding mechanism, robust sample size (>50–100 respondents, depending on size of the communities examined), comprehensive demographic breakdowns, explicit qualitative focus group testing or quantitative pilot testing, justification of econometric model, and clear explanation of results, including aggregate willingness to pay estimates (or at a minimum estimates of central tendency) and the impact of pertinent demographic variables. While failing to adhere to best practice in every single one of these elements may not be enough to dismiss the results of a particular study, 19 of the studies found made enough substantive choices of methodology or execution against the consensus of contingent valuation best practice to warrant their exclusion from this paper’s analysis of results.

Small sample sizes are an unfortunate side effect of the limitations of time and budget, and not necessarily problematic in and of themselves. For instance, Hardner (1996) featured a sample of only 50 respondents, but the study was conducted in a small, demographically homogenous community where that sample size allowed for a realistic reflection of local preferences. However, the sampling strategy used and a justification for it should be included in any contingent valuation study, something the excluded studies failed to do (Arrow et al., 1993; Carson et al., 2001; Johnston et al., 2017; Whittington, 1998; Whittington et al., 1992). In three of the excluded studies, the sample size itself was not included, a particularly problematic oversight.

Many of the excluded contingent valuation studies did not adequately describe the hypothetical market constructed in the study, including the exact water good under consideration, the method by which respondents were to pay for the good, and the means of providing the good. This is troubling, as every one of these factors may have an impact on willingness to pay estimates (Arrow et al., 1993; Carson et al., 2001; Johnston et al., 2017; White et al., 2005; Whittington, 1998; Whittington et al., 1992). For instance, a number of the excluded studies asked how much respondents would be willing to pay for “reliable, clean water,” but not how this water might be obtained. It is possible that the method of payment or means of provision were made clear to the survey’s respondents, but these studies also failed to include a copy of the survey questionnaire in their published findings. While publishing the entire questionnaire would be most useful, at the very least the actual bidding mechanism questions should have been included in the published results (Arrow et al., 1993; Carson et al., 2001; Johnston et al., 2017; White et al., 2005; Whittington, 1998; Whittington et al., 1992).

Finally, a large majority of the excluded studies failed to explain the decision-making process behind their choice of econometric model. Different econometric models require varying degrees of complexity and assumptions of interdependence and can lead to considerably different willingness to pay estimates, so this choice should have been clearly explained and justified in the study’s published results (Arrow et al., 1993; Carson, 2012; Carson et al., 2001; Johnston et al., 2017; Loomis, 2000; Whittington, 1998).
4.1 The extant body of contingent valuation studies of rural potable water systems

The remaining 33 studies examined can be organized for analytical purposes into three broad categories based on the water good being examined: those measuring willingness to pay for the creation of a potable water system (Category A), those measuring willingness to pay for the improvement of an existing potable water system to provide greater reliability (Category B), and those measuring willingness to pay for the improvement of an existing water system to achieve an environmental benefit not directly related to the welfare of water consumers (Category C). The studies under discussion here are shown, broken down by category, in Table 1.

The number of respondents sampled in the studies varied greatly, with the smallest sample size consisting of 50 respondents (Hardner, 1996), and the largest, 2,700 respondents (Ahmad, Goldar, & Misra, 2005). These two studies represent

| TABLE 1 Contingent valuation studies of potable water systems included in analysis |
|------------------------------------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Author and Titus                         | Year           | Country        | Sample size   | Percentage of income for improvement | Percentage of increase in tariff for imp. | Income effect | Education effect | Other variable effect |
|------------------------------------------|----------------|----------------|----------------|-------------------------------------|------------------------------------------|--------------|-----------------|---------------------|
| A. Setting up potable water supply system | Adenike and Titus 2009 Nigeria 142 +3% N/A Increases Increases Married, nonfarmer + |
| Al-Ghuraiz and Emshassi 2005 Palestine 609 +4% N/A Increases Increases Nonrefugee + |
| Altaf, Jamal et al. 1992 Pakistan 662 +3.5% N/A Increases Increases Female, nonfarmers + |
| Annoah 2017 Ghana 609 +6% N/A Increases Not Tested Male, large family, eco awar +, age − |
| Awad and Holländer 2010 Palestine 525 +1.6% N/A Increases Increases Peri-urban, nonrefugee + |
| Banda, Farolfi, and Hassan 2006 South Africa 374 +2% N/A Decreases Decreases Rural + |
| Bogale and Urgessa 2012 Ethiopia 126 +2% N/A Increases Increases Time to get water, female +, age − |
| Farolfi, Mabugu, and Nshingila 2007 Swaziland 374 +0.13% N/A Increases Increases Time to get water, female, age + |
| Hardner 1996 Ecuador 50 +23% (paid in labor) N/A No Effect Not Tested |
| Jianjun, Wenyu et al. 2016 China 168 +0.3% N/A Increases Increases Fewer household members + |
| Lema and Beyene 2012 Ethiopia 132 +0.45% N/A Increases Not Tested Time to get water, reliability of water |
| Mbata 2006 Botswana 135 +13% N/A Increases Increases Nonfarmer, female + |
| Minten, Razafindralambo et al. 2002 Madagascar 180 +5% N/A Increases Increases Other variable effect |
| Ogunniyi, Sanusi, and Ezekiel 2011 Nigeria 120 +16% N/A Decreases Not Tested Female +, age − |
| Orgill, Shaheed et al. 2013 Cambodia 915 +1.2% N/A Increases Increases Other variable effect |
| Tapvong and Kruavan 1999 Thailand 1,020 +1.6% N/A Increases Increases Other variable effect |
| Whittington, Briscoe et al. 1990 Haiti 170 +2.1% N/A Increases Increases Other variable effect |
| Whittington, Lauria et al. 1993 Ghana 1,200 +2% N/A Increases Increases Other variable effect |
| B. Increasing water tariffs (improvement/reliability) |
| Ahmad, Goldar, and Misra 2005 Bangladesh 2,700 +0.3% N/A Increases Increases Own land + |
| Briscoe, de Castro et al. 1990 Brazil 1,232 +2.3% +250% Increases Increases |
| Fujita, Fuji et al. 2009 Peru 1,000 +3.5% +100% Increases Increases |
| Kaliba, Norman, and Chang 2003 Tanzania 450 N/A +89% Increases Increases |
| Peters and Mohamed 2010 Guyana 150 N/A +155% Increases Increases Knowledge of water issues + |
| Peters et al. 2014 Trinidad and Tobago 305 +2.5% N/A Increases Increases Nonfarmer + |
| Vásquez 2014 Guatemala 500 +1.5% +210% Increases Increases Age − |
| Vásquez and Espaillat 2016 Guatemala 500 +3.5% +228% Increases Increases |
| Vásquez, Mozumder et al. 2009 Mexico 398 +5.5% N/A Increases Increases |
| Whittington, Pattanayak et al. 2002 Nepal 1,500 +6.3% N/A Increases Increases |
| C. Increasing water tariffs (environmental benefits) |
| Almendarez-Hernández, Jaramillo-Mosqueira et al. 2013 Mexico 245 N/A +18% Increases Increases Prob. obtaining water, female, fishing co-ops, eco awar +, age − |
| Nallathiga and Paravasthu 2010 India 113 N/A +15% Increases Increases |
| Ojeda, Mayer, and Solomoun 2008 Mexico 148 +1.2% N/A Increases Increases Eco awar +, age − |
| Ortega-Pacheco, Lupi, and Shultz and Soliz 2009 Costa Rica 300 +2% +126% Increases Increases |
| Shultz and Soliz 2007 Bolivia 211 +2% +65% Increases Increases |
substantial outliers in their sample sizes however, with the next smallest and largest having 113 and 1,500 respondents, respectively. The studies collectively had a mean sample size of 525 respondents, which dropped to a mean of 472 respondents when the two outliers are removed. The median survey had a sample size of 374, demonstrating, as can be seen in Table 1, how a few large samples shifted the mean upwards.

The earliest studies under consideration, Briscoe et al. (1990) and Whittington et al. (1990) were published in 1990, while the most recent, Amoah (2017), was published in 2017, with a mean year of publication of 2007. The studies examined were conducted in 26 countries, with the greatest number of studies being from Mexico, with three, while Ethiopia, Guatemala, Nigeria, and Palestine each had two studies undertaken, as seen in Figure 2.

While all of the studies examined here estimated respondents’ willingness to pay for the improvement of the examined potable water good, 29 of the studies (85%) also provided income data for the respondents sampled. This allowed for the calculation of the willingness to pay estimate as a percentage of the respondents' income, which is more useful in a comparative sense, given the wide variation in the incomes of the respondents and overall income and price levels of the countries under examination. Unfortunately, the variation in the exact potable water good under consideration, even within categories, makes direct comparability imprecise, but broad patterns are observable.

Overall, respondents in the studies analyzed expressed a mean willingness to pay of 3.38% of their total household income for the potable water good under consideration. This number does not include Hardner (1996), which measured willingness to pay in labor time cost; that unique study is discussed below in Box 1.

The studies in Category A, examining the willingness to pay for the creation of a new potable water system, estimated a mean willingness to pay of 3.78% of the respondents’ income. These studies also showed the widest divergence in willingness to pay estimates, which might be explained by the greater variance in starting water challenge, variable proposed solutions, difficulty in estimating the value of a more hypothetical good, and the limitations of the respondents' ability to pay on willingness to pay estimates.

The lowest willingness to pay estimates among the Category A studies were Jianjun, Wenyu, Ying, and Xiaomin (2016) at 0.3% of income, Lema and Beyene (2012) at 0.45% of income, and Farolfi, Mabugu, and Ntshingila (2007) at 0.5% of income. Jianjun et al. (2016), conducted in the Songzi area of Hunan province, China, presents an interesting situation, where respondents were supplied with water from a tap, but the water was not actually potable. This lead to respondents almost universally boiling their tap water and listing potability as a relatively low priority (Jianjun et al., 2016). This set of circumstances may have contributed to the exceptionally low willingness to pay estimate. Lema and Beyene (2012), conducted in the Goro-Gutu District of Ethiopia, featured strongly bimodal responses, between households which were directly involved in the set-up of a potable water system and those which were not, with the former having significantly higher willingness to pay estimates. The communities surveyed were also characterized by a high degree of skepticism over the efficacy of the proposed potable water scheme, after the failure of a similar plan in the early 2000s (Lema & Beyene, 2012). Farolfi et al. (2007), conducted in Swaziland, features even more pronouncedly bimodal responses, with the smaller number of respondents living in urbanized areas

![FIGURE 2 Survey locations of contingent valuation studies included in analysis](image)
and having access to private tap water almost universally unwilling to pay anything to establish a potable water system. These respondents substantially pushed down the overall willingness to pay estimate for the proposed improvement (Farolfi et al., 2007).

Conversely, the highest willingness to pay estimates among the Category A studies were found by Ogunniyi, Sanusi, and Ezekiel (2011) at 16% and Mbata (2006) at 13%. Ogunniyi et al. (2011), conducted in Kwara State, Nigeria, featured a small percentage (<20%) of respondents with prior access to privately supplied, potable water, who expressed almost no willingness to pay for the creation of a potable water system, and a much larger number who expressed an exceptionally high willingness to pay estimate for this endeavor. Unfortunately, not enough information is available about local context or the survey procedures to offer a plausible explanation for the exceptionally high willingness to pay estimates from the latter group. Mbata (2006), conducted in Kanye, Botswana, offers a more obvious explanation for its high willingness to pay estimate. The area where the survey was conducted featured relatively high incomes, but virtually no access to potable drinking water, with water-borne illness attributed as a common cause of death, particularly for children. Water stress, possibly due to climate change, contributed to water issues taking on a top priority for the communities studied. Thus, the high willingness to pay estimate is in line with expectations.

The Category B studies, examining the willingness to pay for the improvement of an existing potable water supply system to ensure greater reliability in the quality and/or quantity of water generated, estimated a mean willingness to pay of 3.18% of income. With one exception, the studies in Category B showed a much smaller range of variance than those in Category A or C, likely do the more tangible nature of the good being examined and the much smaller divergence in the hypothetical good being proposed. The exception, Ahmad et al. (2005), featured a low willingness to pay estimate, at 0.3% of household income. However, the study, conducted throughout rural Bangladesh with an exceptionally large sample size (2,700 respondents), asked respondents how much they would be willing to pay for a reduction in the level of arsenic in their water supply system, rather than a more general improvement in quality/reliability or in the health outcomes related to water quality. A number of studies (Arrow et al., 1993; Carson, 2012; Carson et al., 2001; Kim & Cho, 2002; Loomis, 2000; White et al., 2005) have suggested that respondents are able to more validly estimate their willingness to pay for an environmental good when the benefits are directly tangible in health or well-being effects, rather than an abstract improvement. Ahmad et al. (2005) was also the only Category B study to estimate willingness to pay for only an improvement in the quality of the water generated by the extant system, rather than improvement in water quantity, in the form of greater reliability, hours of service, or amount of water generated, in addition to the quality of the water, in the form of safety or taste.

The Category C studies, examining willingness to pay for the improvement of an existing water system to achieve an environmental benefit not directly related to the welfare of water consumers, showed a lower average willingness to pay estimate, at a mean of 1.73% of income. While these studies showed very little variance (a range of 1.2% of income to 2%), only four of the seven Category C studies (57%) provided sufficient income data to calculate this information.

While not all Category B and C studies provided income data, a majority (10 out of 15; 67%) provided existing water tariff data, allowing willingness to pay estimates to be compared against current water expenses. This framing is valuable for these
types of studies, as they are asking respondents to hypothetically increase their water bills, with the tariff explicitly used as the bid vehicle. The Category B studies, involving improvements to existing systems for greater quality and reliability, showed a mean willingness to pay estimate of an additional 172% on top of respondents' current water tariffs for the proposed improvement. These studies again showed relatively little variance, although Ahmad et al. (2005) did not provide water tariff data. Given the relative similarity of the water goods under consideration and their more tangible nature, this lack of variation is not surprising. The Category C studies, involving improvements to existing systems to achieve environmental benefits not directly related to consumer welfare, showed a mean willingness to pay of an additional 56% on top of the current water tariff for the proposed improvement. The only significant outlier was Ortega-Pacheco, Lupi, and Kaplowitz (2009), estimating a willingness to pay of an additional 126% of the respondents' current water tariffs. While this study, conducted in rural eastern Costa Rica, framed the improvement in terms of environmental benefits, the respondents were specifically informed about possible improvements to water quality which they might also benefit from. It is therefore unsurprising that the willingness to pay estimate is closer to those found in Category B studies than the other Category C studies. Given that the Category C studies measured goods which had stronger nonuse than use value to respondents, it is in line with expectations that the willingness to pay estimates generated were lower than those in Category B.

A large majority of the studies (28 studies, 85%), collected demographic information on both the income and education level of the respondents interviewed. In all but one of these studies with both income and education data, higher incomes and levels of education were positively correlated with higher willingness to pay for the examined water good. In three of the studies (Amoah, 2017; Lema & Beyene, 2012 and Minten, Razafindralambo, Burton Randriamiarana, & Larson, 2002), income was also positively correlated with higher willingness to pay, but education was not measured. Hardner (1996) found no effect from higher income on willingness to pay and did not examine education levels. Only two studies found a negative correlation between higher income levels and willingness to pay (Banda, Farolfi, & Hassan, 2006; Ogunniyi et al., 2011) and only Banda et al. (2006) found a negative correlation between higher education levels and willingness to pay, while Ogunniyi et al. (2011) did not examine education levels.

The area surveyed by Banda et al. (2006), the districts around Steelpoort in South Africa, feature exceptionally high inequality in existing water infrastructure, a legacy of Apartheid era infrastructure investment. Ogunniyi et al. (2011), conducted in Kwara State, Nigeria, included respondents who already had access to piped water supplies. In both of the areas surveyed, access to extant private piped supplies of water are strongly concentrated in more affluent and urbanized households, making the proposed public supply of stronger appeal to lower-income respondents.

Most of the studies also attempted to evaluate the impact of other demographic variables on respondents' willingness to pay estimates. Although the variables chosen varied greatly between studies, a number of relatively consistent results emerged. Ojeda, Mayer, and Solomon (2008), Ogunniyi et al. (2011), Bogale and Urgessa (2012), Almendarez-Hernández et al. (2013), Vásquez (2014), and Amoah (2017) found youth to be positively correlated with a higher willingness to pay estimate. Mbata (2006), Farolfi et al. (2007), Ogunniyi et al. (2011), Bogale and Urgessa (2012), and Almendarez-Hernández et al. (2013) found that females expressed a higher willingness to pay than males. Whittington, Briscoe, Mu, and Barron (1990), Farolfi et al. (2007), Bogale and Urgessa (2012), Lema and Beyene (2012), and Almendarez-Hernández et al. (2013) unsurprisingly found that difficulty obtaining water, as expressed in cost, distance, time or number of people involved, was positively correlated with higher willingness to pay estimates. Altfat, Whittington, Jamal, and Smith (1993), Mbata (2006), Adenike and Titus (2009), and Peters, Despot, Ragbarsingh, and Iyer (2014) found that nonagricultural employment was positively associated with a higher willingness to pay. Ojeda et al. (2008), Almendarez-Hernández et al. (2013), and Amoah (2017) discovered that a higher level of ecological awareness was positively correlated with higher willingness to pay estimates. Other variables associated with higher willingness to pay estimates included: nonrefugee status (Al-Ghuraiz & Enshassi, 2005; Awad & Holländer, 2010), being married (Adenike & Titus, 2009), owning one's land (Ahmad et al., 2005) and being a member of a cooperative (Almendarez-Hernández et al., 2013).

Overall, despite differences in local context and water good under discussion, respondents expressed relatively consistent willingness to pay estimates, particularly for Category B and C studies. Where willingness to pay estimates greatly diverged, particular local contextual factors or elements of the study design seem to have played a large role. What can researchers and policy makers take away from this relative homogeneity of responses? One possibility is that respondents might also be expressing the limits of their perceived ability to pay for improved potable water systems, as suggested by Hardner (1996). On the other hand, if these figures, showing respondents willing to pay roughly 2–3.5% of income and a 150–200% increase in water tariff for improvements to system functionality (Category B) and roughly 1–2% of income and a 30–60% increase in water tariff for environmental improvements (Category C) do represent a fairly consistent and accurate estimate of respondent's preferences, this would be valuable benchmark data for policy makers hoping to begin charging water tariffs for a new system or increasing tariffs for an improvement.
THE FUTURE: POTENTIAL PATHWAYS FOR CONTINGENT VALUATION STUDIES

Although the number of contingent valuation studies of rural potable water systems continues to grow, limitations of budget, manpower, and institutional obligations will almost certainly ensure that the large majority of these studies will continue to be small-scale, narrowly targeted surveys. This is not meant to detract from the importance of this work; these studies are essential tools in informed water policy decision-making and still a contribution to the body of environmental valuation literature. However, a number of interesting potential research pathways remain unexplored or under-explored and warrant the attention of researchers looking to increase the utility of future contingent valuation studies.

One of the most appealing qualities of contingent valuation surveys, for both researchers and policy-makers, is their flexibility. With a variety of potential hypothetical markets and bid mechanisms, contingent valuation can be successfully adopted to value any conceivable potable water system and adapted to any local context (Ardila et al., 1998; Boyle, 2003; Carson, 2012). However, this very flexibility limits the potential aggregation and comparability of these studies, since the methodological choices behind the survey's design are so uniquely contextual to the given system and community. Conversely, moving towards uniform study design would impact the usefulness of those contingent valuation studies for local communities and policy-makers. A possible compromise would be focusing on ensuring best-practices in methodological design choices and survey execution, developing a uniform standard for reporting information about respondents' income and demographic characteristics, and clearly noting deviations from standardized practices. Balancing the competing roles of a contingent valuation study as a tool of contextual development practice and a component of the broader development research literature will be a challenging exercise, but ultimately essential for the generation of broader comparative data.

An important concern with contingent valuation surveys estimating the value of necessities, such as potable water, is that the willingness to pay expressed by respondents often represents the limits of their ability to pay, given other demands on limited income. This limitation is generally one of the benefits of contingent valuation, restricting respondents' choices to reflect their real-world capacity to pay for the resource (Ardila et al., 1998; Bateman & Turner, 1992; Boyle, 2003; Carson, 2012; Hanemann, 1994). However, when the good in question is potable water, widely regarded as a basic human right, this proposition becomes more ethically challenging, particularly for studies estimating willingness (and ability) to pay for setting up water supply systems. For this reason, there is a niche to be filled for studies like Hardner (1996), which explore nonmonetary bid vehicles in an attempt to estimate respondents' willingness to pay in the absence of income barriers.

Contingent valuation studies of potable water systems have also been slow to adequately explore how power dynamics within a community impact willingness to pay estimates. Studies tend to treat each individual (or household) as a member of the community differentiated only by factors such as age or income, seldom exploring more complex relationships of dependence and dominance, and how these might impact willingness to pay values. Understanding means of social cohesion and control, in-groups and out-groups, could add substantially to our understanding. The gendered aspect of rural water usage is also often ignored in surveys, since households generally consist of both genders. In most areas featuring limited potable water resources, women provide the bulk of the labor in providing water to the household, and often bear a disproportionate impact from the health consequences of inadequate water quality (Arar, 1998; Cleaver, 1998; Karim, Emmelin, Resurreccion, & Wamala, 2012; Nyong & Kanaaroglou, 1999; Zwartveen, 1994).

Contingent valuation studies of potable water systems must also addresses issues of social or institutional trust, which could impact how respondents perceive methods of payment or means of provision within hypothetical markets, as has been shown in nonmarket valuation studies of other environmental goods (Hamilton, 1995; Jones, Evangelinos, Halvdakais, Iosifides, & Sophoulis, 2010; Jones, Malesios, & Botetzagias, 2009; Kassinis & Vafeas, 2006; Oehlmann & Meyerhoff, 2017; Polyzou, Jones, Evangelinos, & Halvdakais, 2011; Roosen et al., 2015; Speelman, Farolfi, Frija, D’Haese, & D’Haese, 2010; Vij & Narain, 2016). For example, do high levels of perceived corruption lead to lower willingness to pay estimates when government is to provide the potable water system under study?

The question of control is potentially very important to respondents but has largely been ignored in the construction of contingent valuation studies of potable water systems. It is possible that respondents' willingness to pay for the provision of potable water might change substantially depending on the means of provision, particularly if the choices are between a good being provided through a community-managed scheme versus a governmental or private for-profit initiative. If this is the case, contingent valuation studies may have to begin to view the means of provision not simply as a component in market design, but as an important aspect of the good itself, that “community-managed potable water” might have a higher or lower value to individuals than “privately provided potable water.”

By their nature, contingent valuation studies are a snapshot, showing the value of an environmental good at a particular time, in a particular context. While conducting a longitudinal contingent valuation study of a potable water system brings a unique and expanded set of challenges, this sort of study would be particularly valuable in locales facing heightened climate change impacts or pressures on water supply from urbanization or desertification (Milfont, 2012; Pettigrew, 1990).
Only a few studies, found in Category C in the previous analysis (Shultz & Soliz, 2007; Ojeda et al., 2008; Ortega-Pacheco et al., 2009; Almendarez-Hernández et al., 2013) have examined communities where water supply service is reliably available, but heavily subsidized. In many emerging economies, high subsidies contribute to dramatic overuse of water, and a concomitant disincentive to adopt more sustainable water management techniques (Bithas, 2008; Budds & McGranahan, 2003; Kanazawa, 1994; Kumar & Singh, 2001; Myers, 1997; Myers, 1998; Rosegrant & Cline, 2002). Contingent valuation surveys offer an excellent opportunity to measure how much consumers are actually willing to pay for potable water, with contextual information provided about the environmental impact. These studies could also offer a chance to understand how a possible withdrawal of subsidies might impact different sections of a community depending on their income, education, capital investments, or other variables.

Finally, no matter the precise topic, there is an on-going need for more contingent valuation studies of potable water systems conducted with an attention to established best practices. Studies with robust sample sizes, comprehensive demographic breakdowns, extensive pilot testing, and methodological choices balancing a sensitivity to local context with comparability will always be in-demand. These are the studies that stand the best chance of being held up as examples to future researchers, moving the field of environmental valuation forward.

6 | CONCLUSION

The pressures of competing claims to limited resources will continue to force policy-makers in emerging and developing countries into making difficult choices in prioritizing the provision of environmental goods. Any attempt to effectively analyze the costs and benefits of a particular policy choice must involve an understanding of the relative value of the goods at stake. With regards to potable water, the lack of realistic markets for its provision necessitate the use of nonmarket valuation techniques to fill in the gap, and in many cases, contingent valuation surveys will be the optimal method, thanks to their ability to value hypothetical changes and limited prior data requirements.

When properly implemented, contingent valuation studies can estimate the maximum willingness to pay of surveyed individuals, allowing the value of the environmental good to be measured. However, contingent valuation studies require careful attention to the design of hypothetical markets, bidding mechanisms, questionnaire design, sample selection, and statistical model. If implemented without consideration of these features, the estimates generated may be seriously biased or unrealistic.

In this paper, 33 high-quality contingent valuation studies of rural potable water systems were examined, showcasing a number of broad patterns. In every one of the surveys examined, respondents expressed a willingness to pay, often substantially, either for the creation of a potable water system or for improvements to existing system. Studies involving changes to existing potable water systems, showed a higher degree of consistency in their willingness to pay estimates than those studies examining the creation of a hypothetical new system. Higher income, increased years of education, youth, and being female were all positively correlated with higher willingness to pay estimates.

However, too many contingent valuation surveys of potable water systems so far conducted are held back by systematic flaws in methodology and execution, which compromise their usefulness, as was the case with 19 of the extant studies uncovered. The lack of directly comparable metrics, opaque choices of sample size, bidding mechanism, and statistical model, and the failure to pilot test or adequately describe the study’s hypothetical market are among the most troubling problems encountered.

While the expense and time requirements of contingent valuation surveys will necessarily limit the scale of many future studies, there are a variety of fascinating topics waiting to be explored. Studies offering aggregation-oriented methodological consistency, testing new bid vehicles, and addressing the impact of community power dynamics, intercommunal cleavages, gender divides, and impact of subsidies could be especially productive. When properly conducted, contingent valuation studies offer the ability to estimate the value attached to a given quantity and quality of potable water through the direct survey of actual rural users. The ability to estimate this value will only grow in importance as the effects of climate change and urbanization place increasing stress on access to these water resources.

ACKNOWLEDGMENTS

The author would like to thank Gregory Witt (George Mason University) for his kind assistance with the creation of this paper’s figures, and Nadia Johnson (Pennsylvania State University) for her kind assistance with the creation of this paper’s map. The Visual Abstract photo is by Sumit Verma, via Pexels.

CONFLICT OF INTEREST

The author has declared no conflicts of interest for this article.
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FURTHER READING

Alberini, A., & Kahn, J. (2006). Handbook on contingent valuation. Cheltenham: Edward Elgar Publishing.
Feldman, D. (2007). Water policy for sustainable development. Baltimore: JHU Press.
Getzner, M., Spash, C., & Stagl, S. (2004). Alternatives for Environmental Valuation (Vol. 4). London: Routledge.
Nwanze, K. F. (2017). A bucket of water: Reflections on sustainable rural development. Rugby: Practical Action Publishing.
Postel, S. (2014). The last oasis: Facing water scarcity. London: Routledge.

REFERENCES

Adenike, A. A., & Titus, O. B. (2009). Determinants of willingness to pay for improved water supply in Osogbo Metropolis; Osun state, Nigeria. Research Journal of Social Sciences, 4, 1–6.
Ahmad, I., Goldar, B., & Misra, S. (2005). Value of arsenic-free drinking water to rural households in Bangladesh. Journal of Environmental Management, 74(2), 173–185.
Ako, A. A., Shimada, J., Eyong, G. E. T., & Fantong, W. Y. (2010). Access to potable water and sanitation in Cameroon within the context of millennium development goals (MDG's). Water Science and Technology, 61(5), 1317–1339.
Alberini, A., & Cooper, J. (2000). Applications of the contingent valuation method in developing countries: A survey (Vol. 146). Rome: Food & Agriculture Org.
Alcamo, J., Flörke, M., & Märker, M. (2007). Future long-term changes in global water resources driven by socio-economic and climatic changes. Hydrological Sciences Journal, 52(2), 247–275.
Alfnes, F., & Rickertsen, K. (2011). Non-market valuation: Experimental methods. The Oxford Handbook of the economics of food consumption and policy (pp. 215–242). Oxford: Oxford University Press.
Al-Ghuraiz, Y., & Enshassi, A. (2005). Ability and willingness to pay for water supply service in the Gaza strip. Building and Environment, 40(8), 1093–1102.
Almendrez-Hernández, M. A., Jaramillo-Mosqueira, L. A., Avilés Polanco, G., Beltrán-Morales, L. F., Hernández-Trejo, V., & Ortega-Rubio, A. (2013). Economic valuation of water in a natural protected area of an emerging economy: Recommendations for el Vizcaino Biosphere Reserve, Mexico. Interciencia, 38(4), 245–252.
Altaf, M. A., Whittington, D., Jamal, H., & Smith, V. K. (1993). Rethinking rural water supply policy in the Punjab, Pakistan. Water Resources Research, 29(7), 1943–1954.
Amoah, A. (2017). Demand for domestic water from an innovative borehole system in rural Ghana: Stated and revealed preference approaches. Water Policy, 19(1), 46–68.
Anar, N. (1998). Cultural responses to water shortage among Palestinians in Jordan: The water crisis and its impact on child health. Human Organization, 57(3), 284–291.
Andila, S., Quiroga, R., & Vaughan, W. J. (1998). A review of the use of contingent valuation methods in project analysis at the Inter-American Development Bank. Washington, DC: Inter-American Development Bank.
Amnell, N. W. (1999). Climate change and global water resources. Global Environmental Change, 9, S31–S49.
Arrow, K., Solow, R., Portney, P. R., Leamer, E. E., Radner, R., & Schuman, H. (1993). Report of the NOAA panel on contingent valuation. Federal Register, 58(10), 4601–4614.
Awad, I., & Holländer, R. (2010). Applying contingent valuation method to measure the total economic value of domestic water services: A case study in Ramallah Governorate, Palestine. European Journal of Economics, Finance and Administrative Sciences, 20, 76–93.
Banda, B. M., Farolfi, S., & Hassan, R. M. (2006). Determinants of quality and quantity values of water for domestic uses in the Steelpoort sub-basin: A contingent valuation approach (pp. 167–188). London, England: Water Governance for Sustainable Development, Earthscan.
Bateman, I. J., & Turner, R. K. (1992). Evaluation of the environment: The contingent valuation method. Norwich: Centre for Social and Economic Research on the Global Environment.
Bithas, K. (2008). The sustainable residential water use: Sustainability, efficiency and social equity. The European experience. Ecological Economics, 68(1–2), 221–229.
Bogale, A., & Urgessa, B. (2012). Households' willingness to pay for improved rural water service provision: Application of contingent valuation method in eastern Ethiopia. Journal of Human Ecology, 38(2), 145–154.
Boyle, K. J. (2003). Contingent valuation in practice. In A primer on nonmarket valuation (pp. 111–169). Dordrecht: Springer.
Boyle, K. J., & Bishop, R. C. (1988). Welfare measurements using contingent valuation: A comparison of techniques. American Journal of Agricultural Economics, 70(1), 20–28.
Briosco, J., de Castro, P. F., Griffith, C., North, J., & Olsen, O. (1990). Toward equitable and sustainable rural water supplies: A contingent valuation study in Brazil. The World Bank Economic Review, 4(2), 115–134.
Budds, J., & McGranahan, G. (2003). Are the debates on water privatization missing the point? Experiences from Africa, Asia and Latin America. Environment and Urbanization, 15(2), 87–114.
Carson, R. (1985). Three essays on contingent valuation (welfare economics, non-market goods, water quality. (Doctoral dissertation, Ph. D dissertation). Department of Agricultural Economics and Resource Economics, University of California, Berkeley.
Carson, R. T. (2012). Contingent valuation: A practical alternative when prices aren't available. Journal of Economic Perspectives, 26(4), 27–42.
Carson, R. T., Flores, N. E., & Meade, N. F. (2001). Contingent valuation: Controversies and evidence. Environmental and Resource Economics, 19(2), 173–210.
Cleaver, F. (1998). Incentives and informal institutions: Gender and the management of water. Agriculture and Human Values, 15(4), 347–360.
Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... Raskin, R. G. (1997). The value of the world's ecosystem services and natural capital. Nature, 387(6630), 253–260.
Van Rooijen, D. J., Biggs, T. W., Smout, I., & Drechsel, P. (2009). Urban growth, wastewater production and use in irrigated agriculture: A comparative study of Accra, Addis Ababa and Hyderabad. *Irrigation Drainage Systems, 24*, 53–64.

Vásquez, W. F. (2014). Willingness to pay and willingness to work for improvements of municipal and community-managed water services. *Water Resources Research, 50*(10), 8002–8014.

Venkatachalam, L. (2003). Designing contingent valuation (CV) surveys for estimating use values: Some experience from a case study of a water supply project. *Journal of Social and Economic Development, 5*(2), 267–284.

Vij, S., & Narain, V. (2016). Land, water & power: The demise of common property resources in periurban Gurgaon, India. *Land Use Policy, 50*, 59–66.

Vörösmarty, C. J., Green, P., Salisbury, J., & Lammers, R. B. (2000). Global water resources: Vulnerability from climate change and population growth. *Science, 289*(5477), 284–288.

Wada, Y., Van Beek, L. P. H., & Bierkens, M. F. (2011). Modelling global water stress of the recent past: On the relative importance of trends in water demand and climate variability. *Hydrology and Earth System Sciences, 15*(12), 3785–3805.

White, P. C., Jennings, N. V., Renwick, A. R., & Barker, N. H. (2005). Questionnaires in ecology: A review of past use and recommendations for best practice. *Journal of Applied Ecology, 42*(3), 421–430.

Whittington, D. (1998). Administering contingent valuation surveys in developing countries. *World Development, 26*(1), 21–30.

Whittington, D., Briscoe, J., Mu, X., & Barron, W. (1990). Estimating the willingness to pay for water services in developing countries: A case study of the use of contingent valuation surveys in southern Haiti. *Economic Development and Cultural Change, 38*(2), 293–311.

Whittington, D., Smith, V. K., Okorafor, A., Okore, A., Liu, J. L., & McPhail, A. (1992). Giving respondents time to think in contingent valuation studies: A developing country application. *Journal of Environmental Economics and Management, 22*(3), 205–225.

Zwarteveen, M. (1994). *Gender issues, water issues: A gender perspective to irrigation management (No. 32)*. Colombo: IWMI.

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**How to cite this article:** Witt B. Contingent valuation and rural potable water systems: A critical look at the past and future. *WIREs Water*. 2019;6:e1333. [https://doi.org/10.1002/wat2.1333](https://doi.org/10.1002/wat2.1333)