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Rosalina Palanca-Tan
Ateneo de Manila University, rtan@ateneo.edu

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Estimating Residential Water Demand in a Relocation Area with Inadequate Piped Water System

Rosalina Palanca-Tan*

Department of Economics, Ateneo de Manila University, Quezon City 1108 Philippines

This paper assesses household water demand and estimates a demand equation particularly for low-income households in the Philippines. The study uses survey data on the value and volume of household water purchases from different water providers in a government resettlement area. The paper provides empirical evidence on the impact of average water price on household water consumption, as well as the effects of household income and size on household water consumption. The study finds that households buying water from jetmatic pump wells and water tankers pay more than five times that of those served by the piped water system. This much higher cost of water from non-Water District sources could have constrained their water consumption to just about half that of the Water District customers. The estimated water demand equation reveals that demand for water significantly decreases with the average price of water but is only weakly responsive to price changes, with a price elasticity of –0.38. It is also found that water demand is not significantly affected by household income implying that it is not the households' low income but the unavailability of efficient water providers that constrains consumption to a bare minimum. These findings confirm the high vulnerability of low-income households to inadequate and inefficient water providers, necessitating more prudent programming of the resettlement areas' water supply system.

Keywords: income elasticity of demand, price elasticity of demand, residential water demand, water supply systems

INTRODUCTION

Water resource constraint is a global problem that afflicts both developed and developing countries (Lu *et al.* 2017). In recent years, the need for integrated water resources management that concentrates on water demand policies has emerged. As a consequence, there is a growing need for studies estimating water demand functions and demand elasticities. Knowledge of the factors influencing domestic water demand is crucial in the design of water policies and programs, especially in the context of increasing water scarcity (Favre and Montginoul 2016).

*Corresponding Author: rtan@ateneo.edu

Residential demand for water is a particularly challenging concern for the Philippine government. Provision of adequate water is an imperative component of the government's mass housing projects, the centerpiece program in its poverty alleviation efforts (Executive Order no. 20 issued on 28 May 2001). "Clean water and sanitation for all" is the sixth of the 17 Sustainable Development Goals in the 2030 Agenda for Sustainable Development adopted by the United Nations in 2015 (UN Sustainable Development Goals Knowledge Platform). Access to freshwater, in sufficient quantity and quality, is necessary to protect health and reduce the costs associated with water-related illnesses, malnutrition, and losses in productivity. However, the government has been scoring so poorly in this respect. Due to poor planning and inefficiency and probably due to the urgency of the need to relocate, transfer to resettlement areas are commenced even when adequate water supply systems are not yet completely in place.

There is a need to assess residential water demand and understand the factors that affect this demand in low-income resettlement areas so as to aid policymakers in formulating relevant and responsive water provision programs for this segment of the society. Water demand factor elasticities have implications on the adequacy of household water consumption, which has serious health and well-being consequences, as well as on equity among households and between water providers and households.

This paper estimates a water demand equation for low-income households using survey data on the value and volume of household water purchases from different water suppliers in a resettlement site in the Philippines. The paper provides empirical evidence on the relationships between average water price and household water consumption, and between household income and household water consumption by calculating elasticities from the water demand equation. Although literature on water demand estimation and elasticity abound in many countries (see, for instance, the literature review of Espey *et al.* 1997; Arbues *et al.* 2003; Dalhuisen *et al.* 2003; Worthington and Hoffman 2008; Sebri 2014; Abolhasani 2018), such is not the case for the Philippines. To the author's knowledge, the latest water demand study in the country was done by David and Inocencio way back in 1998. Water demand forecasts in the Philippines have been generally based on population estimates and assumptions on per capita water consumption. This paper aims to fill this gap that has prevailed over the past decades. Further, while David and Inocencio's paper (1998) estimated the water demand equation for the whole of Metro Manila with a mix of households from all income levels, this study focuses on low-income households, which may be the first in the water demand literature in the country.

CONCEPTUAL FRAMEWORK

Standard neoclassical demand theory assumes that each consumer maximizes utility, a continuous function of the bundle of commodities the consumer consumes, subject to a budget constraint given the prices of the commodities. The consumer's demand for the commodity is then derived as dependent on the income of the consumer, price of the commodity, availability and prices of related commodities (either substitutes or complements of the commodity under investigation), and other variables reflecting consumer preferences.

Weak separability of water with respect to other goods, implying that water demand does not depend on prices of other goods, is commonly assumed in the literature (Reynaud 2015). Arbues *et al.* (2004) argue that the assumed separability of water with respect to other goods can be justified for three reasons: (1) there are no substitutes for most indoor water uses, (2) household habits may be considered constant at least in the short run, and (3) complementary goods related to domestic water consumption are typically durable appliance (*e.g.* washing machines, bathroom and toilet fixtures, *etc.*) that is unlikely to be changed in the short term in reaction to a water price change.

Thus, the household demand for water (X) can be specified as a function of its price (p), household income (Y), a vector of household characteristics (**Z**), and a vector of all other variables that may have an influence on water demand (**U**):

$$X = X(p, Y, \mathbf{Z}, \mathbf{U}) \quad (1)$$

To analyze the strength of the influence of water price and household income on household water consumption, water demand elasticities are calculated from the estimated coefficients of the water demand equation.

The price elasticity of water demand measures the responsiveness of water demand to changes in its price. Mathematically, it is equal to the percent change in household water demand divided by the percent change in the price of water. Using derivatives, the price elasticity of demand, ε_p, is calculated using the formula:

$$\varepsilon_p = [\partial(X)/X] / [\partial p/p] = [\partial X/\partial p] / [X/p] \quad (2)$$

where $\partial(X)/X$ is the percent change in water demand and $\partial p/p$ is the percent change in price. Rearranging the terms, ε_p can be expressed as the ratio of the derivative function, $\partial X/\partial p$ (the estimated coefficient of p in the water demand equation), to the average function X/p.

Similarly, the income elasticity of water demand, ε_Y, measures the responsiveness of household water use to a change in household income and is calculated as the percent change in household water demand, $\partial X/X$, divided by the percent change in household income, $\partial Y/Y$, or the ratio of the marginal and average functions of water demand with respect to income ($\partial X/\partial Y$ and X/Y, respectively):

$$\varepsilon_Y = [\partial(X)/X] / [\partial Y/Y] = [\partial X/\partial Y] / [X/Y] \quad (3)$$

In general, water demand elasticity with respect to any statistically significant explanatory variable, Z_i, may be calculated and analyzed using the formula:

$$\varepsilon_{Zi} = [\partial(X)/X] / [\partial Z_i/Z_i] = [\partial X/\partial Z_i] / [X/Z_i] \quad (4)$$

Reynaud (2015) points out that water used by households is a composite good that consists of direct (water for drinking) and indirect (water as an input in different household activities such as cooking, washing, gardening, *etc.*) uses. Water may have no substitute and hence a necessity in some of its uses (such as in the case of drinking water) but, in its many other uses, it is not and its demand is likely to be more affected by price.

METHODOLOGY

Study Site

Pandi, a second-class municipality in the province of Bulacan, is one of the major sites for the National Housing Authority's (NHA) resettlement programs. Bulacan is immediately in the north of Metro Manila, the National Capital Region of the Philippines. Pandi, located in the eastern portion of Bulacan, is 45 km northeast of Metro Manila. There are nine resettlement sites in Pandi with a total of 18,673 housing units. These resettlement developments could be the main factor behind the increase in the municipality's population from only 66,650 in 2010 to 89,075 in 2015.

One of the nine resettlement projects is Pandi Residences 2 (Pandi 2), which is located in Barangay Bagong Barrio. Pandi 2 has a total of 2,297 units, 99% of which (2,268) had already been occupied as of 04 May 2018 (NHA Pandi Representative Office 2018 interview). Pandi 2 is about 4.5 km away from the municipality's *poblacion*. Household beneficiaries started occupying units in Pandi 2 in July 2014.

As the water supply infrastructure of the designated water utility, Pandi Water District (PWD), was not yet fully in place when resettled households started moving in, alternative water providers emerged to meet the rapidly growing water demand. General water supply (excluding drinking water supply) systems available in Pandi 2 can be categorized into four: (1) piped water (PWD), (2) water delivery tanks, (3) private jetmatic pump wells, and (4) public hand-pumped wells.

The piped water system involves individual house connections with PWD's groundwater source. Due to delays in setting up the necessary water supply infrastructure for the whole of Pandi 2, only Phase 1 and a small portion of Phase 2 had been served by PWD at the time of the survey. Further, PWD's supply is available for a maximum of only 12 hours a day and has very weak pressure due to the absence of an overhead reservoir. It is also laden with frequent interruption (some lasting for weeks) due to supply system breakdowns. Jetmatic pump wells were put up by some residents to generate water for their own needs and for sale to neighboring households. Water is delivered to neighbors using a plastic hose that extends from the jetmatic pump well to houses a couple of blocks away. Water delivery trucks or tankers were the primary sources of water before PWD's piped water supply commenced in 2015 and jetmatic pump wells became available. Delivery trucks come on a regular basis particularly in areas with no piped water connections and no jetmatic pump wells. Finally, two public hand-pumped deep wells were constructed by the barangay in Phases 4 and 5. Anyone can pump water anytime for free. Nonetheless, access to free water from the public deep wells is constrained by distance and the availability of household members who can fetch and pump water from the public well.

DATA COLLECTION

A household survey was conducted to determine water consumption and the particular water supplier/s availed of by the households. The survey instrument was finalized after a focus group discussion with representative households, and a series of key informant interviews with local government officials (Municipality of Pandi), head of the National Housing Authority (NHA) Representative Office in Pandi and community leaders. These pre-survey activities enabled the researchers to identify and characterize all water supply modalities.

The instrument consisted of three parts. Part 1 asked basic information about the respondent and the household. Part 2, which made up about two-thirds of the questionnaire, contained detailed water-related questions. It started by asking which of the types of water providers available in the area are availed by the household. For each water provider, questions on access, volume, and value of water consumption, water quality, household water treatment method/s (if any), and satisfaction with the provider's service were asked. Part 3 asked socioeconomic questions such as household income, housing assets, consumption, and sanitation. All questions were provided with categorical answers or ranges of values (except for age), from which respondents could choose to make the task manageable for the respondent and the responses to all questions quantifiable. For the household income question, the respondent was simply asked to choose from among income brackets (the highest of which is the open-ended bracket of PhP 100,000 and above), to which the household belongs. Based on the researchers' extensive survey experience, asking household income is generally not a difficult and sensitive task for low-income household surveys in the Philippines.

For this study, a sample size of 50 households – following the statisticians' rule of thumb for a sufficient sample size for ordinary least squares regression – was targeted. This target sample size was distributed equally among the five Phases in Pandi 2, *i.e.* 10 households from each Phase. Respondents in each Phase were chosen using systematic sampling. With a map sourced from NHA, a starting point for each Phase was randomly identified and enumerators were instructed to approach the 40th house from the starting point. The same interval was used for succeeding respondents. The survey was conducted through in-person interviews during the months of October–December 2018. Each household interview lasted about 30–45 min.

Data Analysis

In the paper, household water demand is specified as a function of average water price, household income, and household size. Water demand is measured as the monthly volume of water consumed by the household, excluding drinking water in five-gallon containers purchased from water refilling stations.

The different water supply providers in Pandi 2 have different water pricing systems. The water district, just like other water utilities in the country, follows a progressive block water rate schedule starting with a minimum flat rate of PhP 195.00 for monthly water consumption of 10 m^3 and less (PWD website). Water tankers and jetmatic pump well owners charge prices that vary with the size of the water container. The content in gallons of each container is converted into cubic meters to arrive at the average price per cubic meter of water for each container. The price per cubic meter of water increases with smaller water containers, starting from PhP 120.08 for the large-size 55-gallon drum to PhP 264.17 for a one-gallon pail or basin. Water purchases from neighbors with PWD piped water connections are priced on the monthly bill sharing basis, or on an hourly basis, or by container (just like jetmatic pump well and water tanker), depending on the relationship between seller and buyer.

Water from public hand-pumped deep wells is free of charge. In this case, the effective cost of water may be measured in terms of the time cost of getting water – which consists of the time in going to/from the public well, time in the queue, and time in pumping water. Based on interviews with households accessing this water source, average time for fetching two five-gallon containers of water from the public well is about 15 min. With a minimum wage rate of PhP 355 for an eight-hour work-day in Region 3 – Central Luzon (National Wages and Productivity Commission website 2019), the cost of time for fetching water is estimated to be about PhP 293.65 per cubic meter of water.

With the varying and rather complicated water pricing systems in Pandi 2, only the average price can be calculated for the regression analysis. It has long been recognized in the water literature that most water tariffs have complex structures that combine fixed and variable charges, and the presence of non-uniform prices is always a challenging task in demand estimation. Thus, the average price measure appears to be the main alternative in most studies (Arbues *et al.* 2003). The use of the average price variable is further justified by the observed limited knowledge and understanding of the complex water price structure by consumers. Remarkably, some studies suggest that water demand is more responsive to average price than marginal price, and some other studies suggest that the choice of the price variable does not greatly affect elasticity estimates (Arbues *et al.* 2003).

This study specifies a linear function, a commonly used functional form in the water demand literature. The linear function implies that consumers are less sensitive to price when the price is lower, an assumption that is intuitively appealing and supported to some extent by empirical literature on water demand (Billings and Day 1989). The logarithmic form that results in constant price elasticity of demand (implying constant price sensitivity at low and high prices) is not used for this study due to its lack of consistency with utility theory (Al-Quanibet and Johnston 1985). Further, the study of Abolhasani and co-authors (2018) found that the logarithmic functional specification affects the price elasticity estimate.

This paper employs the ordinary least squares (OLS) technique for the regression. As shown in many literature reviews (see, for instance, Arbues *et al.* 2003 and Abolhasani *et al.* 2018), OLS is the most widely used method in estimating residential water demand. Abolhasani and co-authors' meta-analysis (2018) reveals that the OLS technique results in more robust estimates, *i.e.* its use does not significantly influence the price elasticity estimate.

To establish the suitability of the OLS method, the data sets are subjected to tests for conformity with the OLS assumptions of normality, homoscedasticity, and absence of multicollinearity. The satisfaction of the normality assumption to invoke the Central Limit Theorem also establishes the adequacy of the actual sample size used for the regression. Finally, a correlation test of the error term with each explanatory variable is undertaken to check for simultaneity, a problem that may arise in demand estimation.

RESULTS

Water Consumption Volume and Value, and Effective Water Prices, by Type of Water Supply Provider

As mentioned earlier, the different water supply providers have different water pricing systems, thus resulting in varying the effective price for every cubic meter of water across water providers. Column 2 of Table 1 reveals the distribution of the final sample of 49 households according to the type of main water provider. The main source of water of the majority (27 households) is jetmatic pump well. One of these 27 households is the owner of the jetmatic pump well. As it is hard to isolate its own water consumption from its total water production, this respondent is dropped from the sample, thus reducing the sample size by one. The Water District serves about a third of the respondent households (16 households). Only four of the respondent households source water mainly from water tankers, while two buy water from neighbors connected to the Water District and one mainly fetch water from the public deep well. This distribution reflects the very limited service coverage of the Water District. It also reveals that jetmatic pump well supply is generally preferred over water tankers as the former is more readily available. There is also some pressure for households to buy from a fellow resident and for water tankers not to go to areas with jetmatic pump well.

The average monthly water consumption and payment per household for each type of water provider are presented in columns 3 and 4, respectively, of Table 1. Water payment is divided by water consumption to arrive at the effective water price for each water provider (column 5). The sample of 16 households connected to PWD yields an average monthly water consumption of 11.06 m^3 with an average water bill of PhP 231.67, resulting in an effective water price of PhP 23.73 per cubic meter of water. The two households buying water from neighbors connected to PWD make an average monthly water payment of PhP 450.00 for 6.92 m^3 of water, resulting in an effective cost of PhP 86.46 per cubic meter of water.

The sample of 26 households that mainly source water from a neighboring jetmatic pump well owner makes an average water purchase of PhP 788.63 for 6.18 m^3 of water per month, resulting in an effective cost of PhP 130.39 per cubic meter of water. Monthly purchases from water tankers of the sample of 6 households average PhP 735.00 for average consumption of 5.98 m^3 with an effective cost of PhP 121.48 per cubic meter of water.

Finally, the only respondent household sourcing its water mainly from the public deep well consumes about 3.16 m^3 of water every month at no cash outlay.

Table 1 reveals substantial differences in the financial burden assumed by Pandi 2 residents in meeting their daily water needs. Households buying water from jetmatic pump wells and water tankers pay more than five times for every cubic meter of water compared to households served by the water utility. With the much higher financial cost of water from non-water utility sources, affected households limit their water consumption to about half the consumption of those already served by the water utility. As water is a basic nutritional and hygiene requirement, an overly constrained consumption can have serious health and well-being implications.

Water Demand Estimation

Table 2 presents the descriptive statistics of the variables used in the regression analysis. Overall, the sample of 49 households consume an average of 7.75 m^3 of water per month and pay an average of PhP 90.17 for every cubic meter of water. The average monthly income of the sample households is PhP 21,969. The average monthly income of the sample households of PhP 21,969, when deflated to 2015 prices, is PhP 20,779, less than the average monthly family income in the Philippines in 2015 of Php 22,000 (PSA 2015). On average, each household has five members. Dummy variables for the type of water supplier are also included in the regression analysis. Of the 49 households included in the regression, 53% are mainly sourcing water from jetmatic pump wells (*D_JPuWe*), 8% from water tankers (*D_WaTa*), 4% from neighbors with piped water (*D_NPiWa*), and 2% from the public hand-pumped deep well (*D_PDeWe*). The remaining 33% are connected to the water utility.

Regression tests reveal satisfaction of the OLS assumptions (please refer to the second panel of Table 3). White's test confirms that residuals are homoscedastic and, hence, the estimated OLS coefficients are unbiased and reliable (minimum variance). Mean VIF of 2.36 is much lower than 10 implying that multicollinearity is not a problem, which

Table 1. Effective water prices by water supply providers.

Water supply provider	Number of respondent households	Average monthly water consumption (m^3)	Average monthly water payment (PhP)	Effective water price per cubic meter of water (PhP)
PWD	16	11.06	231.67	23.17
Neighbor connected to PWD	2	6.92	450.00	86.46
Jetmatic deep well	26	6.18	788.63	130.39
Water tanker	4	5.98	735.00	121.48
Public hand-pumped well	1	3.16	0.00(cash outlay)	0.0 (cash outlay); 293.65 (time cost of fetching water)

Table 2. Descriptive statistics.

Variable	Name	Min	Max	Mean	Std. deviation
Monthly water consumption (m^3)	*WaterDd*	0.83	16.46	7.75	4.10
Effective water price (PhP/m^3)	*EffPrice*	0.00	263.16	90.17	60.98
Total monthly household income (PhP)	*HHIncome*	1,500	90,000	21,969	15,311
Household size (no. of household members)	*HHSize*	2	12	5.16	2.94
Dummy for jetmatic pump well	*D_JPuWe*	0	1	0.53	0.50
Dummy for water tanker	*D_WaTa*	0	1	0.08	0.28
Dummy for neighbor's piped water	*D_NPiWa*	0	1	0.04	0.20
Dummy for public deep well	*D_PDeWe*	0	1	0.02	0.14

is also supported by very weak (close to zero) correlations for all pairs of explanatory variables. The Jarque-Bera tests show that both the dependent variable and the error term do not significantly deviate from a normal distribution, implying that the sample size is adequate to invoke the Central Limit Theorem and run an OLS regression. Finally, the residuals are not at all correlated with any of the explanatory variables (all correlation coefficients are 0.0000) and, hence, simultaneity is not likely a problem. Arbues and co-authors (2003) note that the simultaneity problem is usually considered an empirical issue, dependent on the particular context and data set.

Table 3. Water demand regression results, ordinary least squares method.

Explanatory variable	Coefficient	*p*-value	Demand elasticity
EffPrice	–0.03350	0.040	–0.3899
HHIncome	–0.00001	0.718	–
HHSize	0.52652	0.025	0.3578
D_JPuWe	–1.35167	0.492	–
D_WaTa	0.11599	0.963	–
D_NPiWa	–1.11639	0.761	–
D_PDeWe	–9.74797	0.015	–
Constant	9.28550	0.000	–
R2	0.4426	–	–
Adj R2	0.3474	–	–
F-stat	4.65	0.001	–
Tests			–
Jarque-Bera normality test for dependent variable C_W	1.802	0.4062	–
Jarque-Bera normality test for residuals r	1.61	0.4465	–
White's test for Heteroscedasticity	24.69	0.2134	–
Mean VIF	2.36	-	–

For instance, Taylor (1975) – in estimating electricity demand – noted that the tariff structure is independent of consumption in the short-run and hence the simultaneity issue was irrelevant and could be ignored. The same can be said of the water pricing structures of the various water supply providers in Pandi 2.

The water demand regression results (first panel of Table 3) reveal that the effective price of water and the size of the household are statistically significant determinants of households' water demand. In conformity with economic theory, demand for water is lower the higher the price of water. Specifically, when water is cheaper by PhP 1, the monthly water consumption of the household is higher by 0.0335 m^3. Intuitively, household size has a statistically significant positive impact on water demand – an additional member in the household increases its monthly water consumption by 0.5265 m^3. Household income does not have a statistically significant effect on water demand. For the dummy variables for the type of supplier, only the public deep well system turns out to be statistically significant. Its coefficient indicates that demand for water from the public deep well system would be about 9.75 m^3 lower than the demand for piped water. This reflects the inconveniences and the high time cost of fetching water from the public deep wells even if the cash outlay for this water source is nil. It is noted that even households residing just a few meters away from the public deep wells buy water from jetmatic pump wells or water tankers.

Demand elasticities with respect to each of the two statistically significant explanatory variables are given in the fourth column of Table 3. Demand for water is price inelastic as water is a basic necessity. People will continue to buy water no matter what the price is, putting them at the mercy of the available suppliers and, hence, the need for an active government role in the sector. The inelastic demand with respect to household size, on the other hand, reflects economies of scale in household water use. If the number of household members doubles, for instance, water demand increases but less proportionately.

CONCLUSION

This paper provides empirical evidence on water demand and its elasticities for the particular case of low-income households in the Philippines. The study finds that demand for water in this government resettlement area significantly decreases with the average price of water but is only weakly responsive to price changes, with an estimated price elasticity of –0.38. This means that a 10% increase in the average price of water will only induce a 3.8% reduction in water consumption. This estimate is within the range of values, –0.2 to –0.5, derived by David and Inocencio (1998) for Metro Manila, Philippines in 1998, and the range –0.3 to –0.6 in the literature review of Nauges and Whittington (2010) for developing countries. Most recent studies in low-income communities in developing countries likewise result in weakly-price responsive water demand. In Tunisia, Favre and Montginoul (2016) estimated the price elasticity of demand to be just -0.1 for piped households and even 0.0 for non-piped households. Abolhasani and co-authors (2018) surveyed 21 empirical case studies in Iran with 65 estimates of price elasticity for residual water demand ranging between –0.428 and –0.312. A vast literature on residential water demand in developed countries also found water demand to be generally price-inelastic. Espey and co-authors (1997) reviewed 124 price elasticity estimates from 24 residential water demand studies in the United States and found that 90% of the estimates ranged between 0 and –0.75 and the average of all estimates was just –0.51. Dalhuisen and co-authors' (2003) survey of 64 studies with 314 estimates of price elasticity of water demand had a mean of –0.41 and a median of –0.35 while Sebri's (2014) most recent meta-analysis of price elasticity of water demand estimates had a mean of –0.365 and a median of –0.291. Lu and co-authors (2017) observe that despite the heterogeneity in data and estimation techniques, water demand studies done over the years suggest that water demand, in general, is price inelastic and a 10% increase in water price generally results in a 3–5% reduction in water consumption. The insensitivity of the demand for water to price changes is attributed to the nature of water as a basic necessity with no close substitute, the generally limited awareness of people about the water rate structure, and the water bill's relatively small share in household income (Arbues *et al.* 2003).

This study also found that household income does not significantly affect water demand. Favre and Montginoul (2016) obtained the same result, concluding that among non-piped households with very low water consumption levels, water demand appears to be driven by variables characterizing the physical accessibility to the water source, rather than income of the household. This scenario is similar to Pandi 2's case where about two-thirds of the residents still do not have access to piped water.

The findings of the study reveal the high vulnerability of low-income households to an inadequate and inefficient water supply system. While the price-inelastic water demand reflects the nature of water as a basic necessity with no close substitute, it also underscores the helplessness of low-income households. Pandi 2 households will maintain their barely minimum water purchase no matter what the price is, putting them at the mercy of the available suppliers. Hence, the study serves to highlight the greater need for more prudent programming of the water supply system and for choosing a water utility with an established and good-performing record for the resettlement areas. It also calls for some controls for price and quality standards of small-scale water providers that cater to low-income communities.

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