The costs of delay in infrastructure investments

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Water Resources Research

RESEARCH ARTICLE

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Key Points:

- Average household coping costs more than doubled in Kathmandu in real terms over the period from 2001 to 2014, from US\$5 to US\$12 per month
- Household coping costs were widely distributed throughout all income groups in the population in both 2001 and 2014
- For households with private connections, by 2014 their monthly coping costs were approximately 4 times greater than their water bill

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The costs of delay in infrastructure investments: A comparison of 2001 and 2014 household water supply coping costs in the Kathmandu Valley, Nepal

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Abstract In 2001, we conducted a survey of 1500 randomly sampled households in Kathmandu to determine the costs people were incurring to cope with Kathmandu's poor quality, unreliable piped water supply system. From 2001 until 2014, there was little additional public investment in the municipal water supply system. In the summer of 2014, we attempted to reinterview all 1500 households in our 2001 sample to determine how they had managed to deal with the growing water shortage and the deteriorating condition of the piped water infrastructure in Kathmandu and to compare their coping costs in 2014 with those we first estimated in 2001. Average household coping costs more than doubled in real terms over the period from 2001 to 2014, from US\$5 to US\$12 per month (measured in 2014 prices). The composition of household coping costs changed from 2001 to 2014, as households responded to the deteriorating condition of the piped water infrastructure by drilling more private wells, purchasing water from both tanker truck and bottled water vendors, and installing more storage tanks. These investments and expenditures resulted in a decline in the time households spend collecting water from outside the home. Our analysis suggests that the significant increase in coping costs between 2001 and 2014 may provide an opportunity for the municipal water utility to substantially increase water tariffs if the quantity and quality of piped services can be improved. However, the capital investments made by some households in private wells, pumping and treatment systems, and storage tanks in response to the delay in infrastructure investment may lock them into current patterns of water use, at least in the short run, and thus make it difficult to predict how they would respond to tariff increases for improved piped water services.

1. Introduction

In 2001, we conducted a survey of 1500 randomly sampled households in Kathmandu to determine the costs people were incurring to cope with Kathmandu's poor quality, unreliable piped water supply system and to estimate their willingness to pay for improved piped water services [Whittington *et al.*, 2002; Pattanayak *et al.*, 2005]. At the time, there were two related policy and infrastructure changes under consideration that motivated our study. The first was the proposal to construct the Melamchi Water Supply Project (MWSP), a US\$464 million package of infrastructure investments designed to bring water from the Melamchi River into the Kathmandu Valley [Whittington *et al.*, 2004]. The project involves an interbasin water transfer of about 170,000 m³/d to be delivered through a 26 km long tunnel through a mountain. The second intervention being discussed by international donors was the possibility of engaging a private sector operator to manage the municipal water supply system. Both sets of projects, once completed, were expected to help improve piped water services in the Kathmandu Valley.

Our 2001 study found that about 70% of the residents of Kathmandu Valley had a connection to the piped distribution network, but they typically received nonpotable water for only 1–2 hours per day (h/d). Households were incurring coping costs of about US\$5/month (m) (in 2014 prices), approximately 2% of

household income. Our 2001 estimates of coping costs had five components: (1) the value of time spent collecting water, (2) pumping costs from private wells, (3) in-household water treatment costs, (4) storage costs, and (5) payments for water purchased from vendors and others. The largest of these components was the value of time spent collecting water from outside the home, and these time costs were higher for poor households than for non-poor households. These coping costs were almost twice as much as the typical water bill of households connected to the piped water network and about 20% of their stated willingness to pay for improved services (24 h/d, 7 days a week).

From 2001 until 2014, there was little additional investment in the municipal water supply system except for the MWSP. From 1996 until 2006, Nepal experienced political turmoil (the royal family was murdered by the Crown Prince) and civil war; as a result, there was rapid population growth in Kathmandu Valley due to massive in-migration. Additionally, Nepal's economy has been one of the slowest growing in South Asia, and there have been difficulties in negotiating financing for new investments in urban infrastructure. As a result, progress on the MWSP has been much slower than expected. After years of discussion, in 2000 the Asian Development Bank (ADB) and its partners finally agreed to finance the MWSP. However, the World Bank pulled its support in 2002, due in part to the government's failure to engage a private operator in the management of the municipal water supply system. Construction of the Melamchi tunnel did not begin until 2009. The project experienced further delays due to problems with the first contractor. At the time of our second survey in 2014, residents of Kathmandu still had not received any additional water supplies from outside the Kathmandu Valley. Most of these issues have now been resolved. New water supplies are expected to reach Kathmandu after the completion of Melamchi tunnel in 2017; associated investments in the rehabilitation and expansion of the water supply infrastructure in Kathmandu are scheduled for completion by 2020.

In the summer of 2014, we attempted to reinterview all 1500 households in our 2001 sample to determine how they managed to deal with the growing water shortage and the deteriorating condition of the piped water infrastructure in Kathmandu and to compare their coping costs in 2014 with those we first estimated in 2001. Our broad objective was to understand and quantify the costs to households of delaying investments in piped water supply infrastructure in a large, rapidly growing city in a low-income country. Kathmandu's experience over the 13 years from 2001 to 2014 is not unique. Because piped water supply infrastructure is so capital intensive [Whittington *et al.*, 2009], it takes time to design, finance, and build large projects, but political stability and economic growth are essential for sustaining the investment process and cannot be taken for granted. Many cities in developing countries have experienced similar "lost decades" of investment in water supply infrastructure due to financial crises, civil war, or political turmoil [Swyngedouw, 2004].

In section 2, we describe the water supply infrastructure in 2001 and how it changed up to 2014. Section 3 presents the background for understanding household decisions about coping costs, as well as a review of the literature on coping costs as an estimate of the benefits of environmental quality improvements more generally. Section 4 describes our modeling strategy and method for calculating coping costs. Section 5 discusses the 2014 fieldwork and presents a profile of sample households, contrasting their socioeconomic situation in 2001 and 2014. It also compares the water supply conditions of households in 2001 and 2014, both those connected to the piped water network and those that were not. In section 6, we then present the 2014 household coping costs estimates and compare these with our 2001 results. We also compare and contrast the 2014 coping costs of households with different water supply conditions and of different income groups. Section 7 presents the results of multivariate analyses of the factors associated with the change in coping costs from 2001 to 2014. Section 8 summarizes our conclusions about the costs of delay in the Kathmandu municipal water sector.

2. Background

In 2014, the population of Kathmandu Valley was approximately 2.7 million. The population of the urban areas of the Kathmandu Valley—Kathmandu metropolitan city, Lalitpur submetropolitan city and the municipalities of Kirtipur, Madhyapur, and Bhaktapur—have experienced especially rapid growth, from 674,000 in 2001 to 1,141,000 in 2014. Much of this increase was due to in-migration as people fled from the civil war in the rural areas and sought safety and better economic opportunities in the Kathmandu Valley [Muzzini and Aparicio, 2013]. The 2011 census reported that 44% of the total population in the valley was in-migrants from other parts of the country, mainly rural and other small urban areas [Suwal, 2014]. The

population density of urban areas in the Kathmandu Valley increased as people crowded into the city, from 10,262 persons/km² in 2001 to 14,703 in 2011 [Subedi, 2014]. This in-migration was accompanied by unplanned construction on the edges of the city as agricultural lands in the valley were converted to urban uses, especially housing.

The Nepal Water Supply Corporation (NWSC) oversees the municipal water supply and sanitation sector in the Kathmandu Valley [Bhandari, 2014]. The NWSC is owned by government (30%), municipalities (50%), private entities (15%), and employees (5%) [Bhandari, 2014]. Kathmandu Upatyaka Khanepani Limited (KUKL) is the service operator and provider in the Kathmandu Valley, with a service area of 150 km² [Bhandari, 2014]. KUKL currently manages 35 surface sources, 59 tube wells, 47 ground reservoirs, and 21 treatment plants [Bhandari, 2014]. KUKL lacked both the funds and the institutional capacity to respond effectively to the growing water crisis in the Kathmandu Valley, but providing piped water and sewer services to this rapidly growing, unserved population would have challenged even a well-financed, well-managed water utility.

Over the past two decades, Nepal's economic growth rate has lagged most other countries in South and East Asia [World Bank, 2016]. Nevertheless, by global standards, over the past 5 years Nepal's annual GDP growth rate has averaged a respectable 4.5%, and household incomes in Kathmandu have been steadily increasing [World Bank, 2016]. But this economic growth did not translate into significant increases in funding for the rehabilitation and expansion of KUKL's water and sanitation infrastructure. Little international donor assistance stepped in to fill the gap. From 2002 to 2004, KUKL received a grant from Japan for about US\$25 million to improve KUKL's municipal water facilities (i.e., the Manohara Water Treatment Plant, Min Bhawan and Singha Durbar Elevated Tanks, and the distribution line from the Shaibhu Reservoir to Lalitpur) [Kathmandu Upatyaka Khanepani Limited, 2015]. Aside from the ADB's support of the MWSP, this was the only significant foreign assistance to the municipal water sector.

The origins of the MWSP date back to Kathmandu's 1973 Water Master Plan, which identified the need for new out-of-valley raw water sources [Binnie and Partners, 1973]. The Master Plan argued that in-valley water sources were inadequate to meet long-term needs and that out-of-valley sources should be studied [Binnie and Partners, 1973]. Feasibility studies were conducted from 1988 to 1992 [Binnie and Partners, 1988; Snowy Mountain Engineering Consultants, 1992] on the option of bringing water from Melamchi River, situated outside the valley, through a 26 km-long tunnel. The first phase of this project was estimated to be able to supply an extra 170,000 m³/d and subsequent phases up to a total of 500,000 m³/d [Pant et al., 2008].

In 2000, the ADB awarded a loan to Nepal to help finance the US\$464 million MWSP, conditional on institutional reforms, which included a private operator [Domenech et al., 2013]. Failure to attract private bidders resulted in a long delay in the MWSP. The ADB approved a major restructuring of the financing package for the MWSP, allowing the project to move forward [Domenech et al., 2013]. The private sector participation requirement was removed, as well as some of the social development initiatives in the original project [Asian Development Bank (ADB), 2008]. The ADB provided a US\$137 million loan, Japan Bank for International Cooperation provided an additional US\$47.5 million, and several other donors participated in the financing with smaller amounts [ADB, 2008]. The government of Nepal promised to provide domestic counterpart financing of US\$90.6 million. The revised project was estimated to cost US\$317 million [ADB, 2008]. Originally, this revised MWSP was to be completed by the summer of 2016, but contractor delays and the 2015 earthquakes have pushed back the completion date to 2017.

The result of this low level of investment in the municipal water supply infrastructure during this period has been that by 2014 urban residents of the Kathmandu Valley faced acute and recurrent water shortages and deteriorating water quality. Although KUKL managed to increase the number of residential connections from 167,000 in 2008, to 195,000 in 2013 [Kathmandu Upatyaka Khanepani Limited (KUKL), 2014], the total amount of water supply did not increase as the additional raw water from the MWSP had not yet arrived. KUKL [2014] estimates that it needs 360,000 m³ of water per day to supply its existing customers. However, KUKL [2014] is only able to supply 150,000 m³/d in the wet season and 90,000 m³/d in the dry season. Thus, even when the first phase of the MWSP is completed, KUKL will still not be able to supply 360,000 m³/d.

Households have responded in two main ways to KUKL's inability to increase supplies. First, many drilled private wells to supplement their water supply from KUKL's piped network. Second, households began purchasing increasing quantities of water from a new, rapidly growing private water vending industry. In 2001,

there were only about 60–70 tankers in the Kathmandu Valley, with most operated by KUKL. By 2004, the number of tankers had grown to about 160, and five large-capacity boreholes had been drilled to supplement the tanker trucks' use of natural water sources. Between 2004 and 2008, the number increased by an additional 500 tankers. By 2014, 210 firms engaged in water vending and operated about 700 water tankers.

In 2014, there were also approximately 200 bottled water firms in Kathmandu selling water mostly in 20 L plastic bottles ("jars"), in addition to the smaller 1 L bottles. In 2004, there were only about 5 bottled water enterprises. The Nepal Bottled Water Association (a trade association with 160 of the 200 registered firms in Kathmandu Valley) reports that today, only 25% of the drinking water used by households is supplied by KUKL.

In summary, from 2001 to 2014 the private sector has stepped in to meet the growing household demand for improved water services. In the next sections of the paper, we describe in more detail what these changes have meant to households in terms of increased monthly costs and inconvenience.

3. A Review of the Theory and Literature on "Coping Costs"

The theory underlying the relationship between the coping costs that a household incurs in dealing with unreliable, nonpotable water supplies and its demand for improved water supplies comes from the environmental economics literature on the measurement of the benefits and costs of pollution control [Mäler, 1974; Mäler and Wyzga, 1976; Cropper and Oates, 1992]. The costs of coping, or averting, behaviors (such as purchasing air conditioners to reduce exposure to air pollution) are used to estimate the value of environmental quality improvements.

We present a simple theoretical framework to illustrate the relationship between coping costs and the economic benefits of improvements in a public water supply system. We follow closely the approach described in Pattanayak *et al.* [2005]. We assume the household has a health production function and seeks to maximize its utility [Bartik, 1988; Larson and Gnedenko, 1999; McConnell and Rosado, 2000; Pattanayak *et al.*, 2005; Cook *et al.*, 2016b].

The household combines inputs of labor, money, capital, and environmental goods to produce utility-yielding services, conditioned on household preferences (θ). A representative household faces the following utility maximization problem:

$$\max_{T_L, T_C, M, Z} U(T_L, Z, S(C(T_C, M), W(G)); \theta) \quad (1)$$

$$s.t. \quad T = T_W + T_L + T_C + S \quad (2)$$

$$N + wT_W = pM + Z \quad (3)$$

The household values leisure (T_L), a composite consumption good (Z), and health (S), all of which enter directly into the utility function (equation (1)). Health is characterized by the number of sick days, which are a function of the public water supply (W) and coping behaviors (C). The public water supply (W) and coping behaviors (C) are assumed to enter the household's utility function only by promoting health. The public water supply is a function of government policies (G), such as infrastructure provision. If the water supplied by the government is not of adequate quality, quantity, or reliability, households choose a variety of coping behaviors (C) by spending time (T_C) and money on market commodities (M) related to water.

The household faces both a time and a budget constraint. Earned income is limited by the total amount of time available to the household (T), which is spent on work (T_W), leisure (T_L), coping with the limitations of the public water supply system (T_C), and being ill (S) (equation (2)). Spending on the composite consumption good (Z) and market commodities related to water (M), with prices 1 and p , respectively, must equal total income, which is the sum of exogenous income (N), such as returns on capital and remittances, and earned income, which is the product of the hourly wage (w) and the number of hours worked (T_W) (equation (3)).

Households maximize utility by choosing how much time to devote to leisure (T_L), paid labor (T_W) and coping (T_C), how much of the composite good (Z) to consume, and how much to spend on market

commodities (M) related to coping with an inadequate water supply. The water supply service level is assumed to be exogenously determined by the government; households cannot choose their current water supply regime [Cook *et al.*, 2016b]. However, if the quality, quantity, or reliability of the services from the public water supply system change ($W(G)$), due, for example, to new infrastructure investment, the household's optimal choices will also change.

This theoretical framework helps us answer the question, "How much does a household value an improvement in the public water supply system from the status quo $W(G_0)$ to an improved situation $W(G_1)$?" Using duality theory, the utility maximization problem can be transformed into a cost minimization problem to obtain a utility constant willingness to pay (WTP) measure—the change in exogenous income that will compensate for a marginal change in public water supply services [Pattanayak *et al.*, 2005]. This WTP measure, $\frac{\partial \Omega}{\partial W}$, can then be described as the sum of the following three components:

$$\frac{\partial \Omega}{\partial W} = \left[p \frac{\partial M}{\partial W} + w \frac{\partial T_c}{\partial W} \right] + w \frac{\partial S}{\partial W} - \lambda \frac{\partial U}{\partial S} \frac{\partial S}{\partial W} \quad (4)$$

where Ω is the expenditure function in the cost minimization problem, and $\frac{\partial \Omega}{\partial W}$ is the amount of exogenous income, dN , that could be taken away from the household to compensate for the change in utility ∂U as a result of a change (an improvement) in water services ∂W , holding the household at the initial welfare level, U^0 . The three terms that form the WTP function are (1) the coping costs in terms of financial expenditures and lost value of time spent coping, (2) lost value of time spent ill, and (3) monetary value of being ill [Cook *et al.*, 2016b]. In this paper, our estimation of coping costs only includes the first term—the financial expenditures on commodities related to water (e.g., purchases of vended water, point-of-use water filters) and the value of time spent coping.

This simple theoretical framework assumes households trade leisure time for work and that the wage rate is the marginal compensation for sacrificing time for money. Therefore, the incremental value of time is indicated by the wage rate [von Wartburg and Waters, 2004]. However, there is a rich literature on the value of time that has made many conceptual advances over this simple theoretical construction. This literature shows that there are many situations in which the household's value of time will not approximate its wage rate. From example, if its members cannot control the number of hours they work at the market wage, time savings may not be easily converted to income, and the value of time saved in nonmarket activities will be less than the wage rate [von Wartburg and Waters, 2004]. Boardman *et al.* [2010] review the literature on the value of time spent in different nonwage activities and find that in many cases the values of time are approximately 50% of after-tax wages. Most of these studies have been conducted in industrialized countries and examine tradeoffs households make between money and commuting time. However, there are a few studies from low-income countries that look specifically at the value of time households spend collecting water from outside the home. A discussion of these studies and how our study handles the value of time is carried out in the next section.

Researchers observe the expenditures that households make on "coping strategies" to address the problems caused by unreliable, poor quality public water services. They then use these observational data to obtain a lower bound on household willingness to pay for improved water services. Economists typically interpret estimates of coping costs as a lower bound on households' willingness to pay for environmental services for three reasons. First, households might be willing to pay more for service improvements but the market prices for coping activities are lower than their maximum willingness to pay. Second, there are often additional residual damages. In the case of households coping with unreliable, poor quality water supplies, 24/7 potable water from a private water connection would be an unambiguously better service than the service they can achieve through the coping expenditures. Third, estimates of coping costs typically cannot practically include all of the theoretically plausible coping cost expenditures.

A portion of the coping cost literature focuses on water pollution in the United States [Abdalla, 1990; Collins and Steinback, 1993; Laughland *et al.*, 1993]. However, our focus is on the literature that applies the theory of coping costs to urban water supply in developing countries. The review of this literature identifies (1) empirical drivers of demand for improved water supply and (2) theoretical refinements in the simple household production function model. Papers in this literature use regression analysis (either ordinary least squares or maximum likelihood estimators) to estimate the association between household coping costs

and different covariates. These researchers have faced a common challenge. Heterogeneity in household preferences may introduce systematic errors and bias the estimates of coefficients. Our data give us an opportunity to address this problem in a way that has not been used in the literature previously.

Most of the literature on coping costs and household demand for improved water services uses cross-section observational data. There are only a few field experiments with randomly assigned interventions [Pattanayak *et al.*, 2013; Jalan and Somanathan, 2008; Kremer *et al.*, 2011; Ashraf *et al.*, 2010]. Most papers use cross-section observational data to examine the discrete choices households make to cope with unreliable, poor-quality public supplies and use random utility models to describe household choices [Madajewicz *et al.*, 2007; Jessoe, 2013; Vásquez, 2012; Katuwal and Bohara, 2011; Vásquez *et al.*, 2009; Abrahams *et al.*, 2000; Um *et al.*, 2002; McConnell and Rosado, 2000; Larson and Gnedenko, 1999]. The independence of irrelevant alternatives assumption used in this literature is difficult to defend because some coping methods are arguably close substitutes (boiling, filtering, purchasing bottled water). However, these papers do provide guidance on which explanatory variables can be used to capture technology, tastes, and quantity of water use, which together define the coping cost function [Pattanayak *et al.*, 2005].

For example, the literature shows that perceptions of the water quality, quantity, and reliability of piped water supplies affect coping costs. Abrahams *et al.* [2000], Larson and Gnedenko [1999], and Um *et al.* [2002] all find a significant association between coping costs and perceptions of water quality. Madajewicz *et al.* [2007] find a significant association between coping costs and the provision of water quality information. Vásquez *et al.* [2009] and Vásquez [2012] find a significant association between coping costs and households' perceived reliability of the piped water supply. Household socioeconomic and demographic characteristics are also commonly included in household models of coping cost decisions, e.g., education, number of children, age, income, and wealth [Larson and Gnedenko, 1999; McConnell and Rosado, 2000; Katuwal and Bohara, 2011; Vásquez, 2012].

Different household water sources are also described in these models. Pattanayak *et al.* [2005] use explanatory variables that describe whether the household has a private water connection, the number of water sources used, and whether the household uses community sources. Jessoe [2013] and Cook *et al.* [2016b] similarly include explanatory variables to describe a household's primary drinking water source. Vásquez *et al.* [2009] include variables for storage and bottled water use.

One theoretical concern with the models of coping costs in the literature is that averting behaviors may provide the household utility through different pathways [Bartik, 1988; Cropper and Oates, 1992]. For example, Abrahams *et al.* [2000] found that in Athens, Georgia (USA) water quality differences other than health risk (e.g., taste, odor, and appearance) between the public supply and bottled water led to a 12% overestimate of households' willingness to pay for the health benefits of improved water quality. Pattanayak *et al.* [2005] note that all of the various water sources used by households in Kathmandu have quantity, reliability, and quality dimensions, and that they can only include proxy variables for unit prices, household production, technology, and tastes. Given the numerous water sources used in Kathmandu, they caution that it is not possible to identify household willingness to pay for improvements in different attributes of the public water supply from their data.

In a second study of coping costs in Kathmandu, Katuwal and Bohara [2011] model household coping strategies. Like Pattanayak *et al.* [2005], they use cross-section observational data on household coping behaviors. Katuwal and Bohara [2011] find that wealth, perception of the quality of water piped connections to the public distribution supply, and exposure to information all have statistically significant effects on coping costs.

Our study makes two contributions to the literature on household coping costs in the municipal water supply sector. First, we describe how coping behaviors and costs have changed over an extended period (from 2001 to 2014) in a city whose inhabitants have experienced rapid population growth and political instability, in addition to a deteriorating water supply infrastructure. By revisiting the same households interviewed in 2001, this study describes how the economic costs experienced by households have changed as a result of a lack of investment in the municipal water supply infrastructure at the same time that private investment in the water vending industry and wells has increased.

Second, our research design allows us to examine population heterogeneity in taste parameters. Because we have data on the same households in 2001 and 2014, we can use differences in household coping cost estimates as the dependent variable and thus control for time invariant household-level unobservables,

such as taste preferences that have not changed from 2001 to 2014. This strengthens the validity of our analysis of the determinants of coping behaviors and costs.

4. Coping Costs Modeling Strategy and Calculation

4.1. Modeling Strategy

Coping cost functions, similar to the cost functions of firms, depend on unit prices of inputs and outputs, conditional on production technology and household preferences or tastes [Pattanayak *et al.*, 2005]. Proxy variables are used to capture time-varying tastes, technology, and the quality of water used by the household. We replicate, with some modifications, the analysis done by Pattanayak *et al.* [2005] with the 2001 Kathmandu coping cost data, and we estimate a linear regression model relating total coping costs ($copingcosts_{it}$) to the set of observables in which we are interested (household demographic characteristics, water source characteristics, quality perceptions, and policy preferences). However, unlike Pattanayak *et al.* [2005], we are able to use two cross-sectional data sets. Additionally, we add to the model the respondent's gender, reliability of the private water connection as measured by hours of service, having a private well, and quality perceptions, as suggested by the more recent coping cost literature. Equation (5) illustrates our coping cost model, which uses differences between variables in 2014 and 2001 to eliminate unobserved factors that do not change over time:

$$\begin{aligned} copingcosts_{i2014} - copingcosts_{i2001} &= \beta_1(hh_char_{i2014} - hh_char_{i2001}) + \beta_2(water_char_{i2014} \\ &- water_char_{i2001}) + \beta_3(perceived_quality_wet_{i2014} \\ &- perceived_quality_wet_{i2001}) + \beta_4(perceived_quality_dry_{i2014} \\ &- perceived_quality_dry_{i2001}) + \beta_5(policy_pref_{i2014} - policy_pref_{i2001}) \\ &+ u_{i2014} - u_{i2001} \end{aligned} \quad (5)$$

Important household demographic characteristics (vector hh_char_{it}) include income, education, gender, and number of children. Water source characteristics (vector $water_char_{it}$) include having a private water connection, having a private well, having both a private water connection and a private well, reliability of the private water connection, and number of water sources used. Quality perceptions (vector $perceived_quality_{it}$) are respondent ratings of taste, dirtiness, health risks, and reliability of piped water in year t ($t = 2001$ or $t = 2014$) in both the wet and dry seasons. Policy preferences ($policy_pref_{it}$) describe the respondent's belief about whether water issues were the most serious environmental policy problems faced by the residents of Kathmandu Valley. Stochastic components (u_{it}) capture the idiosyncratic effects of unobserved factors.

4.2. Calculation of Coping Costs

We disaggregate coping costs into the costs associated with five coping behaviors: (1) collection time, (2) private well construction and operation, (3) water storage and rainwater collection, (4) in-house water treatment, and (5) monetary payments to water vendors and other informal suppliers. Our categorization and calculation of coping cost components differs from the 2001 construction by Pattanayak *et al.* [2005]. Rainwater collection system costs are separated from private well construction and operation and placed with water storage because these systems often share equipment. The lifespan of all equipment has been changed to be 20 years, instead of 15 years for wells and 30 years for rainwater systems and storage equipment. We next describe the calculation of the costs of each of these five components. We do not include estimates of costs of illness because we are not able to accurately attribute medical expenditures to poor water and sanitation conditions.

4.2.1. Collection Costs (Time Spent)

In our household interviews, we collected data to estimate the time households spend collecting water from outside the home. Household members spend time walking to and from water sources outside the home, as well as waiting at a source. Our households report an average of 1.2 water collectors per household. Six hundred and ninety-four households have only one collector, 149 have two, and three households have three water collectors.

We estimate the costs of time spent collecting water by multiplying the self-reported amount of time by an assumed shadow price of time. Some might argue that time savings from not having to collect water would only have an economic value to households if they were devoted to income-generating activities. However, there are numerous reasons why households would be willing to pay for time savings that could result

from improved water services besides devoting the time savings to paid labor, e.g., increased leisure, child-care, food preparation, as well as schooling and preventative health activities.

We did not undertake a separate study to estimate the shadow price of time in Kathmandu. Rather, we look to other studies in the literature where researchers estimate the economic value households place on time savings from not having to collect water. This benefit transfer approach (i.e., of transferring estimates of the shadow price of time from other study sites to the policy study site of interest—in our case Kathmandu) is common in economic analyses that need to estimate the economic value of nonmarket outcomes such as the time spent collecting water [Boardman *et al.*, 2010].

Cook *et al.* [2016a] provide a comprehensive overview of estimates of the value of travel time in low-income countries. They begin with an overview of studies from the transportation sector, which find value of time estimates ranging from 18–86% of wages. Cook *et al.* [2016a] also review three papers that value time within the context of water collection. Whittington *et al.* [1990] find a value of 100% of unskilled wages in a small Kenyan town, even though there was no evidence that these time savings would be devoted to paid labor. Asthana [1997] find a value of 35% of the unskilled wage rate in rural India, and Kremer *et al.* [2011] estimate a value of travel time of only 7% of the unskilled wage rate in rural Kenya. Cook *et al.* [2016a] themselves use a stated preference choice experiment to estimate a household-specific value of time spent collecting water. Their results from a random-parameters logit model suggest an average value of time spent collecting water of 18 Ksh/h (US\$0.21 per hour), approximately 50% of the market wage rate. Using a latent class model, these authors find considerable heterogeneity in the value of time spent collecting water across four different groups of households. The first group (about one third of respondents) values time very highly (49 Ksh/h). A second, poorer group values time hardly at all (less than 1 Ksh/h). The third and fourth groups value time at approximately 9 Ksh/h.

In another study, DeVoto *et al.* [2012] find that in Tangiers, Morocco, households' willingness to pay for the time savings and convenience associated with private water connections is high compared to public taps but not because a private connection improves health or opportunities for paid labor. Instead, these authors find that households are willing to pay for a private water connection because it increases the time available for leisure and reduces both inter- and intrahousehold conflicts over water.

These studies provide strong evidence that many households place a positive value on the time spent collecting water. None of these estimates of the value of time rely upon evidence that households would devote time savings from not having to collect water to paid labor or income-generating activities. In fact, DeVoto *et al.* [2012] show that households place a monetary value of time savings devoted to non-income producing activities, including leisure. Based on these results, we believe that it is reasonable to assume that many households in Kathmandu likely place a monetary value on the time they spend collecting water from outside the home, even without evidence that these time savings would be allocated to paid labor or other income-generating activities. For our estimates of coping costs in Kathmandu, we rely on Cook *et al.*'s [2016a] findings from Meru, Kenya.

As in Pattanayak *et al.* [2005], our 2014 estimates of the value of time spent collecting water are household-specific and distinguish between households with domestic servants and those without. For households without domestic servants, we assume a value of time equal to 50% of the average hourly wage of employed individuals in the household. For households with domestic servants, the value of time spent collecting water is assumed to be the average wage rate of the lowest paid individuals in the neighborhood where the household is located. For respondents that did not report an income ($N = 57$), the value of time spent collecting water is assumed to 50% of the median household mean hourly wage in the neighborhood. (Other missing variables were dealt with similarly.) The average hourly wage was estimated from self-reported monthly income assuming a six day work week and 10 h working day. The average hourly wage for households in the 2014 sample was 89 NPR (median 78 NPR), about US\$0.93 (based on a 2014 exchange rate of 95 NPR to US\$1).

We emphasize that these are assumptions about the value of time spent collecting water in Kathmandu and are not based on any empirical data from our household survey. To show the sensitivity of our coping cost estimates to these assumptions about the value of time spent collecting water, we also present estimates of household coping costs in both 2001 and 2014 assuming that the value of time spent collecting water is zero (Table 4). These coping cost estimates that assume a zero value of time are best viewed as a lower bound of what households are willing to pay for improved services.

Respondents reported the distance from their home to a water source in either meters (m) or minutes (min). For those who report the distance in meters, we assumed a walking speed of 80 m/min to estimate the time spent walking to the source. For respondents that did not report time or distance to a source, the median distance to the same type of source of other households in the neighborhood was assumed. The total time spent for one trip from the home to a water source was the round-trip walking time plus the self-reported queuing time at the water source.

4.2.2. Private Wells and Pumping

The monthly household costs of private wells consist of capital and operation and maintenance expenses. The annual capital costs were estimated by multiplying the value of the capital asset (as estimated by the respondent to be the present day replacement value of the capital good) by a capital recovery factor based on the life of the asset and a real discount rate of 10% (private wells and electric pumps were both assumed to have a lifespan of 20). Operation and maintenance costs include self-reported, ongoing minor repairs and electricity use.

Households without private wells also reported owning pumps. These were often used to extract water directly from the piped water system. Their capital and operation and maintenance expenses are also calculated.

4.2.3. In-House Water Treatment Costs

Households incur water treatment costs for both boiling and filtering. Filtering may entail additional household expenditures for equipment; boiling typically does not. We estimated the monthly capital costs for the water filters using the same approach as for private wells and rainwater collections systems. Annual operation and maintenance (O&M) costs are based on self-reported monetary expenditures.

The costs of boiling water are based on estimates from *Tiwari* [2000]. Households in our 2001 and 2014 surveys were asked the frequency with which they boiled their drinking and cooking water (e.g., “almost always,” “occasionally,” and “rarely or never”), and the monthly household costs of boiling are adjusted depending on the respondent’s answer. Using the International Monetary Fund’s inflation index for average consumer prices in Nepal [*International Monetary Fund*, 2015], *Tiwari*’s 1998 estimate for the costs of boiling water (95 NPR/month) is equivalent to 282 NPR in 2014. Households that answered “almost always” are assumed to incur boiling costs of 282 NPR/month, and households that answered “occasionally” are assumed to incur boiling costs of 141 NPR/month. There were no households in our sample that reported that they “rarely or never” boiled their drinking water.

4.2.4. Household Storage and Rainwater Harvesting Systems

Households can purchase overhead or underground storage tanks. Monthly capital costs of water storage assets are calculated based on reported replacement costs, a 20 year economic life of the facilities, and a 10% real interest rate. If a storage tank is shared amongst households, only a proportion of the total cost was assigned to the respondent’s household.

Rainwater harvesting systems are centered around a water storage container, such as a barrel, bucket, or tank, and are therefore included in this section. The monthly capital costs of rainwater collection systems are again calculated assuming a 20 year economic life and a 10% real interest rate.

4.2.5. Monetary Payments to Water Vendors and Other Suppliers

To calculate total household coping costs, we added the monetary payments the household made to private water tankers, bottled water vendors, and public utility tankers, to the estimated monthly costs it incurred for the other four coping cost components described above. Monetary payments made to neighbors are also included, as well as any payments made to access water from stone taps. Payments households made to obtain water from public taps and wells are not included in the coping costs but are categorized as public costs paid by households, similar to household water bill payments. At some water sources outside the home, households made a monetary payment to obtain water. The latter are included in the coping cost component “monetary payments to water vendors and informal suppliers” (not in the estimates of the coping costs associated with collection time).

In Kathmandu households may pay for water from public taps in several ways. In some cases, KUKL provides a “public” tap that is shared by a designated group of households. KUKL provides these households a fixed monthly water bill regardless of the volume of water used. This water bill is then shared by these households. There are also situations where a community association constructs a storage tank and fills it with water from public taps owned by KUKL or with water from the ancient system of stone taps. In this case the

community association may collect a fixed monthly fee from households to pay for management expenses. The community association may charge a minimal fee for maintenance and management of the storage facility. Other community associations work together to build a community storage tank, and purchase water from tanker truck vendors to fill the storage tank. In this case, households are typically charged for each bucket they collect. Again, we distinguish between payments households make to the public utility (KUKL) for both private connections and use of public taps, as well as payments to water vendors and informal suppliers. The former are not included in the estimates of coping costs, but instead are reported separately.

4.3. Summary

As described above, we include annualized capital costs for household investments in private wells and pumps, water storage, and in-house water treatment systems in our estimates of household coping costs. One common theoretical formulation of the coping cost model assumes that there are no significant adjustment costs associated with reducing the level of investment in defensive measures [Bartik, 1988] and that household coping behaviors do not include any large, discrete capital expenditures to avert damages. If coping strategies do not involve capital expenditures, they can be easily stopped, i.e., households have low adjustment costs. For example, a household purchasing water from vendors makes periodic, regular expenditures to cope with unreliable, poor quality water services, but these expenditures can be quickly reversed if a new improved piped water service is installed. In this case the coping cost expenditures represent potential cost savings and will be a theoretically-defensible lower bound on the household's willingness to pay for the improved piped water system.

On the other hand, some authors incorporate capital expenditures in their estimates of coping costs [Abdalla, 1990; Cook *et al.*, 2016b; Pattanayak *et al.*, 2005]. In Kathmandu, many households incur capital costs to ameliorate the consequences of unreliable, poor quality public supplies. These capital costs are not quickly reversible (i.e., have higher adjustment costs), and they are best characterized as sunk costs in the short term. Once such capital investments have been made, the short-run marginal costs of using them may be low. Therefore, for a household that has already made such investments, the short-run cost savings of switching to a new improved public system with 24/7 potable water supply will be much less than, for example, a household relying largely on bottled water vendors.

Because our calculations include annualized capital costs, it is not possible to confidently interpret them as lower bound estimates of households' willingness to pay, at least in the short run. In particular, households with the complete suite of private capital investments (private well and pumping systems, storage, and in-house water treatment systems) would experience relatively modest financial cost savings in the short run from switching all their water use to an improved (24/7) potable private water connection.

Because our estimates of coping costs may not reflect potential cost savings in the short run, they cannot be interpreted as lower bound estimates of household willingness to pay. However, we choose to include annualized capital costs in our estimates of coping costs for two reasons. First, by including capital costs, our coping costs estimates better illustrate long-run demand for improved public water supplies. Households' capital investments in private wells and pumps, storage, and in-house water treatment systems will not last indefinitely. Households will certainly achieve substantial cost savings and better service from switching to an improved public system after the MWSP is complete rather than reinvesting capital in private coping solutions.

Second, households with private wells may face the prospect of additional capital costs sooner than expected. Groundwater levels in Kathmandu have been falling and declines in well yields have become common [Pandey *et al.*, 2012]. Some households with private wells may soon find that they can no longer reach the groundwater and will need to dig (drill) a deeper well, incurring additional capital costs.

5. Description of Study Site, Fieldwork, Sample Households, Existing Water Collection Practices, and Perceptions

5.1. Fieldwork

The 2001 household survey was designed to obtain a representative sample of 1500 households in the five municipalities of Kathmandu Valley: Kathmandu, Lalitpur, Bhaktapur, Kirtipur, and Madhyapur. Households were selected using a multistage cluster sampling procedure. In Nepal, the ward is the lowest level

administrative unit. There are nine wards in a Village Development Committee (VDC) and more than nine wards in municipalities (the precise number depends on the size of the population). In the first stage of the multistage cluster sampling procedure, we followed the common practice among survey researchers in Nepal and considered the ward as the primary sampling unit (PSU). For example, the Nepal Demographic and Health Survey (DHS), Nepal Living Standard Measurement Survey (LSMS), and Nepal Labor Force Survey (NLFS) all used the ward as the PSU. We selected wards based on a population-proportionate-to-size procedure, using the number of households in each ward. This ensured that in the first stage households had an equal probability of being included in the sample [Babbie, 1990].

In this first stage, wards were located using aerial maps provided by the Central Bureau of Statistics for the 1996/97 World Bank Living Standard Measurement Survey for Kathmandu. In three of the five municipalities in the Kathmandu Valley (Kathmandu, Lalitpur, and Bhaktapur), a previously conducted complete enumeration of all households was used to estimate the population of the wards [SILT Consultants and Development Research and Training Center, 1999]. In Kirtipur and Madhyapur, the 1991 population census was used to approximate population size.

In the second stage, we subdivided each ward selected in the first stage into groups of 25 households (termed a “cluster”). Large wards thus had more clusters than smaller wards. Field supervisors, working with enumerators, created maps that identified these clusters of 25 households in each selected ward. The required number of clusters to be selected in the second stage was determined by the total sample size, and clusters were selected randomly.

In the third (final) stage, if a cluster was selected for inclusion in the sample, then respondents from all 25 households in that cluster were interviewed. The final sample consisted of 60 clusters of 25 households each covering all five municipalities in the Kathmandu Valley (1500 total households).

In the 2014 resurvey of the 2001 households, if we were unable to locate the original household, a nearby household was selected for an interview. If the household head from a 2001 sample household was missing, the present head or a responsible member of the house was interviewed instead. In total we were able to locate and reinterview 927 of the 1500 households from the 2001 survey. In the 2014 survey, there are thus 573 replacement households. Figure 1 shows the location of the sample households in the 2014 survey in the Kathmandu Valley, both the matched and replacement households.

Although the 2001 households were a representative sample of the population in the five municipalities in Kathmandu Valley, the sample from the 2014 resurvey is not. Households that migrated to Kathmandu over the period from 2001 to 2014 are not part of our 2014 sample unless they happened to be included as a replacement household. For all the descriptive analyses presented in the paper, we compare the 2001 households with all of the 2014 households (i.e., including both the matched and replacement households). However, replacement households were excluded in the regression analysis in order to control for unobserved household taste parameters.

Fieldwork was conducted over a three-month period from August to October 2014 (the rainy season in Kathmandu). Nineteen experienced enumerators were hired and trained. They conducted the interviews under the supervision of senior field supervisors from the Institute of Population and Development Studies, in Kathmandu, Nepal.

5.2. Profile of Sample Households

Table 1 presents the demographic and socioeconomic characteristics of the overall 2001 and 2014 samples. Table 1 also presents a simple typology of four types of households based on their use of the two main water sources in Kathmandu (for 2014, percentage of sample noted in parentheses): (1) no private water connection and no private well (5% of the sample households); (2) private water connection and no private well (40% of the sample households); (3) no private water connection and private well (6% of the sample households); and (4) private water connection and private well (49% of the sample households). As shown, household heads are naturally older in 2014, increasing from 46 to 57 years of age. Years of education have also increased, from 7 years of education for the head of household in 2001 to 8 years of education in 2014. The percentage of male respondents decreased from 63% to 52%; the percentage of respondents who are married decreased from 85% to 78%. Household sizes are smaller in 2014, reflecting both children leaving home and the demographic transition to smaller families. In 2001, the average household size was eight; in

Figure 1. Location of sample households in Kathmandu Valley—2014 Survey.

2014, it was five. The percentage of households with domestic servants decreased. In both 2001 and 2014, home ownership, electricity coverage, and phone coverage (both landlines and mobile phones) are very high. Sewer connections increased from 71% to 90%. Monthly electricity bills decreased in real terms, but monthly phone bills increased.

Household incomes are measured as the estimated total monthly cash income of all wage earners and self-employed individuals in the household and other possible sources: rental income, pension and/or government cash transfers, and other income from interest, dividends, capital gains, etc. We do not include subsistence agriculture production or barter transactions. Real incomes of sample households have increased by 35% over the 13 year period, from 42,000 NPR per month (adjusted to 2014 NPR) to 57,000 NPR; and the estimated average real market value of the households' dwellings have nearly doubled—from 6.1 million NPR to 11 million NPR.

5.3. Existing Water Collection Practices and Perceptions

Focusing on our entire 2014 sample (i.e., with replacement), we find that households reported that they have access to an average of 4.1 water sources (median 4, range 1–8 sources). They actually used an average of 2.6 sources (median 3, range 1–6 sources), with 85% of households using two or more sources. The two water sources most used by households in 2014 were private water connections (PWCs) and private wells. Overall, approximately 30% of household water supply volume used by sample households comes from private connections, 29% from private wells, 20% from tankers, 8% from public wells, 6% from public taps, and the rest (7%) from neighbors, bottled water (20 L jars), stone taps, and surface water. On average, sample households self-supplied or purchased 85 liters per capita per day (lpcd) in the rainy season and 69 lpcd in the dry season. The median amount self-supplied or purchased in the rainy season was 48 lpcd and 41 lpcd in the dry season. (Note that these water use figures are based on respondents' recall of how much water they used per day from each source in both the rainy and dry seasons. We do not consider these to be precise estimates of household water use due to the difficulties many respondents are likely to have recalling the amounts of water collected, especially from private connections and private wells.)

Compared to 2001, the number of households with neither a PWC nor a private well has decreased from 22% to 5% of the sample, while the percentage of households with both a PWC and private well has increased from 19% to 49%. In 2014, households with neither a PWC nor a private well use the least amount of water (35 lpcd in the dry season). Households with only a PWC use less water (45 lpcd, dry season) than do households with only a private well (69 lpcd, dry season). Households with both a PWC and private well

Table 1. Demographic and Socioeconomic Profile of Sample Households, by Type (2001, 2004)

	2001					2014				
	No PWC, No Private Well	No PWC, Private Well	PWC, No Private Well	PWC, Private Well	Overall	No PWC, No Private Well	No PWC, Private Well	PWC, No Private Well	PWC, Private Well	Overall
Number of households	334	166	710	290	1500	68	94	600	733	1500
Percent of total households %	22	11	47	19	100	5	6	40	49	100
Age of household head, (years)	44	43	43	49	46	53	52	57	57	57
Education of household head, (years)	4	8	8	10	7	4	6	7	9	8
Percentage of respondents who are male %	63	59	64	63	63	44	35	56	53	52
Percentage of respondents who are married %	87	88	84	86	85	75	82	79	77	78
Household size (number of people)	7.8	7.4	8.0	8.3	7.9	5.1	4.7	5.1	5.1	5.1
Monthly household income, 2014 NPR (thousands, adjusted)	21	41	44	62	42	36	40	48	68	57
Property value, 2014 NPR (millions, adjusted)	1.7	7.7	7.4	7.6	6.1	3.5	5.3	7.5	15.1	11.0
Percentage of respondents who are homeowners %	92	88	85	88	88	79	56	93	96	92
Percentage of households that have domestic servant(s) %	2	15	12	19	11	0	7	2	9	6
Percentage of households that have electricity %	93	98	100	100	98	100	98	100	100	100
Monthly electricity bill, 2014 NPR (adjusted)	546	1448	1331	2024	1314	455	790	679	1,129	897
Number of cellphones						2.9	3.0	3.1	3.3	3.2
Monthly phone bill, 2014 NPR (adjusted)	115	1100	959	1579	912	734	948	1136	1506	1238
Percentage of households that have a sewer connection %	47	47	84	30	71	76	61	93	92	90
Amount of water collected (L/capita/d dry season)	12.4	3.6	6.2	3.6	6.8	35	69	45	94	70
Amount of water collected (L/capita/d wet season)	12.9	4.5	7.1	2.8	7.2	34	74	53	114	85
Number of sources used	1.7	1.9	2.0	2.5	2.0	2.7	2.3	2.6	2.7	2.6

use the most water (94 lpcd, dry season). These amounts cannot be compared with 2001 data because estimates of the amounts of water from PWC and private wells were not collected in the 2001 survey. The World Health Organization suggests a minimum safe water requirement of 20 lpcd for basic needs (cooking and drinking) in emergency situations, and 70 lpcd for washing, cleaning, laundry, growing food, and sanitation [Reed and Reed, 2013]. Even though the average water consumption levels in Kathmandu are above these WHO minimums, the quantity of water many households acquire is below these amounts and the quantity of water obtained is neither reliable nor of good quality. Additionally, the water use of 16% of our sample falls below even the minimum safe water requirement during the dry season.

Households that have both a PWC and a private well tend to be richer, with a monthly income that is nearly double that of the other groups. They also live in houses with much higher market values, have higher electricity and phone bills, and are more likely to have domestic servants. These patterns are similar to those in 2001, but the socioeconomic disparities were less extreme between the four types of households in 2014.

Figure 2 shows the average amount of water used by household type and how much water comes from each source during the dry season. The proportions are calculated as a population average of households in each group. Households with neither a PWC nor a private well collect their water from a variety of sources, mainly tankers, public wells, and public taps. Those with a PWC but no private well obtain most of their water from PWCs, supplementing their water supply with water tankers and public wells. Households with a private well but no PWC obtain most of their household water from their private well. Households with both private wells and PWC often obtain additional water from tankers. Across all four types of households, the quantity of water purchased from tankers is similar, ranging from 36 to 48 lpcd in 2014 and 7 to 61 lpcd in 2001 (see Table 2). Households with a private well (both those with and without a PWC) are using substantially more water than households without a private well.

Households' water supply situation and their responses to the growing water shortage have changed from 2001 to 2014. The number of households in the matched sample that had private connections and private wells grew significantly from 2001 to 2014. Over a third of the households that did not have connections in 2001 managed to get connected by 2014 (138 out of 338 households). However, fourteen percent of households with connections in 2001 stopped using their private water connection in 2014 (84 out of 589 households). Twenty-three percent of households that had a private well in 2001 stopped using their well in 2014 (57 out of 249 households). Twenty-four percent of households that did not have a private well in 2001

Figure 2. Quantity of water collected by source and household type in the dry season (2014).

managed to obtain one by 2014 (163 out of 678 households). Reasons why households would stop using their PWCs and private wells could be due to a lack of water, increased contamination, or both.

We asked households to estimate how much water from each source was required for each household task (drinking, cooking, bathing, washing and cleaning). Sample respondents report that most water sources are used for more than one task. On average, households report 1.35 to 1.46 sources used for each task. Piped water and public taps are used mostly for cooking and drinking; public

wells are used mostly for bathing and washing. Water from neighbors is most commonly used for cooking; private wells and tanker water for bathing and washing. Ninety-nine percent of households that use 20 L jars report that it is used for drinking. A typical household with the median household income (42,000 NPR), median water consumption per capita (40 lpcd), and median number of water sources used (three), uses most of the water from their PWC for drinking and some for cooking. This household also uses vended water from tankers for bathing, washing, and other purposes. Finally, they also purchase 20 L jars for drinking.

Table 3 presents households' perceptions of the quality and reliability of water from different sources for the 2001 and 2014 household surveys. For the rainy season, households interviewed in 2014 report that quality (taste and dirtiness) and reliability of water from different sources have generally improved compared to 2001. However, more households report negative perceptions of health risks for PWCs, public wells, private wells, surface waters, and rainwater. On the other hand, the quality (taste, dirtiness, health risks) and reliability in the dry season have declined compared to 2001. However, fewer households report negative perceptions about the dirtiness of water from neighbors, private wells, and vendors. There are also decreases in the percentages of households reporting highly negative perceptions about the reliability of water from PWCs, public taps, neighbors, and vendors.

Table 2. Amount Collected by Type and Year (L/capita/d, Dry Season)

	2001										2014									
	No PWC. No Private Well		No PWC Private Well		PWC. No Private Well		PWC, Private Well		Total		No PWC. No Pri- vate Well		No PWC Private Well		PWC. No Private Well		PWC, Private Well		Total	
	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N	L	N
PWC															29	416	29	572	29	988
Public taps	6	156	5	14	5	102	4	12	6	284	12	39	11	29	14	99	7	6	13	173
Public wells	8	131	3	4	6	160	4	7	7	302	18	38	20	12	16	174	19	18	17	242
Neighbors	7	104	4	81	4	230	3	70	4	485	38	3	17	11	8	62	10	57	10	133
Private well													70	70			77	549	76	619
Tankers	54	6	7	11	61	22	48	14	46	53	37	24	48	14	36	260	45	190	40	488
Stone taps	10	54	5	10	7	97	4	15	8	176	21	6	5	5	17	17	21	14	17	42
Other surface water sources	7	73	4	9	9	7	17	1	7	90	11	6	11	7	19	8	8	3	13	24
Bottled water	0	1	1	6	1	17	2	5	1	29	2	17	2	42	2	169	2	301	2	529
Total	12	334	4	166	6	710	4	290	7	1500	35	68	69	94	45	600	94	738	70	1500

Table 3. Respondents' Perceptions of Water Quality From Available Sources, by Year and Season (Percentages of Respondents That Have a Highly Negative Perception)

Source/Quality	Poor Taste				Very Dirty				Serious Health Risks				Unreliable			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014	2001	2014
Private water connection	53	33	11	24	17	7	3	5	25	33	6	32	10	8	38	24
Public taps	42	13	5	5	11	2	1	2	19	9	4	8	6	1	18	13
Public wells	28	30	13	31	7	3	3	5	12	23	6	21	3	1	4	27
Neighbors that give water away	36	13	9	12	14	1	4	1	16	14	5	13	14	9	35	24
Private well	40	37	31	37	12	2	10	2	25	44	20	44	2	0	4	8
Vendors/tank	16	18	6	16	5	1	5	0	13	16	11	15	20	5	20	9
Stone spouts	6	5	2	4	1	2	1	1	2	4	1	5	2	5	6	33
Other surface water sources (river/stream/lakes)	26	23	21	17	8	2	7	0	5	22	3	18	7	2	9	28
Rainwater	32	45	23		5	2	5		12	28	11		70	71	76	
Bottle mineral water									9	1	9	1				
Jar water (20 L)										1		1				

We expected the quality and reliability of most water sources to decline from 2001 to 2014 due to lack of public sector investment and increased population and economic pressure on existing supplies. The link between deteriorating quantity and quality of water from the piped distribution arises because of the negative pressure in the intermittent piped system, allowing contaminated groundwater to enter the distribution systems. Of course, households interviewed in 2014 do not report that the quality (taste, dirtiness) and reliability of the main water sources (private connections, private wells, and vendors) are good, just that they are not as bad as in 2001. We do find increases in percentages of households reporting perceived health risks from private connections, private wells, and vendors.

Another big change is that households are using much more water from tanker truck and bottled water vendors in 2014 than in 2001. In 2001, 53 sample households purchased water from tankers, compared to 505 households in 2014. There was also a large increase in the purchase of bottled water. In 2001, 30 sample households purchased bottled water compared to 529 households in 2014.

6. Household Coping Costs (2001 Versus 2014)

In this section, we describe our main findings. We first present our overall 2014 estimates of household coping costs for the entire sample. Then, we discuss the 2014 coping costs and their components using our household typology described in the last section. With this baseline, we then explore how coping costs have changed from 2001 to 2014. Next, we examine differences in coping costs between households with different income levels. Finally, we compare household coping costs to public costs paid by taxpayers/donors and to the costs paid by households for public water supplies (i.e., water bills and payments for water from other public sources).

Table 4 presents our 2014 estimates of household coping costs and our recalculated 2001 estimates. Estimates for 2001 were recalculated to allow for consistent comparison between 2001 and 2014 as described in section 4. Table 4 breaks down the coping costs by coping method, type of household (regarding PWC and private well), and by year for the entire sample. For each average cost estimate, only the expenditures of households that use the coping method are included, which is why the sample size varies and the columns cannot be summed. The average household incurs costs of 1206 NPR (US\$12) per month coping with the poor quality, unreliable public water supply system. Most households incur costs associated with storing (384 NPR, $N = 1368$), private wells and pumping (277 NPR, $N = 1214$), treating (165 NPR, $N = 1065$), and purchasing (547 NPR, $N = 958$). Some households also incur time costs associated with collecting water (569 NPR, $N = 433$).

In 2014, households without a private water connection and without a private well spent 1269 NPR on coping costs. Households with only a private water connection spent only 906 NPR per month. Households with only a private well spent the most—1687 NPR per month. Households with both a private water connection and a private well spent 1382 NPR per month.

Table 4. Coping Costs, by Types and Year (2014 NPR)

		2001		2014		Difference	
		NPR	N	NPR	N	NPR	N
No PWC, no private well	Collecting	388	332	902	64	553	67
	Pumping		0	66	14	45	17
	Treating	125	89	109	33	64	34
	Storing	65	32	162	47	135	50
	Buying	543	10	392	42	392	42
	Total	451	334	1269	63	929	63
No PWC, private well	Total (without collecting)	66	334	420	63	334	63
	Collecting	401	102	1215	52	465	75
	Pumping	117	166	456	76	343	32
	Treating	253	116	16	50	56	67
	Storing	201	90	422	63	246	76
	Buying	2333	11	475	60	416	62
PWC, no private well	Total	316	166	1637	94	1100	94
	Total (without collecting)	570	166	1016	94	736	94
	Collecting	348	442	404	252	−112	512
	Pumping		0	93	415	30	423
	Treating	152	433	136	333	26	462
	Storing	142	446	267	554	206	570
PWC, private well	Buying	1325	20	493	412	447	413
	Total	443	710	906	600	433	600
	Total (without collecting)	231	710	737	600	534	600
	Collecting	516	96	364	65	−356	396
	Pumping	95	290	369	709	315	716
	Treating	175	256	191	599	3	709
Overall	Storing	239	229	433	704	337	717
	Buying	825	6	623	444	510	452
	Total	626	290	1332	733	762	733
	Total (without collecting)	455	290	1350	733	954	733
	Collecting	334	972	569	433	−121	1050
	Pumping	103	456	277	1214	233	1243
	Treating	168	949	165	1065	13	1272
	Storing	167	347	334	1360	272	1413
	Buying	1378	47	547	953	472	974
	Total	524	1300	1206	1500	632	1500
	Total (without collecting)	275	1500	1041	1500	766	1500

For the 68 households without either a PWC or a private well, almost all households ($N = 64$) incur most of their coping costs from collection costs (averaging 902 NPR per month). Forty-two households in this group purchase water and their purchasing costs are substantial (392 NPR). Pumping, treating, and storing costs are smaller, with less than half of the households using these coping methods.

The 94 households without a PWC but with a private well incur the highest coping costs, with much of that coming from collection costs. The average household collection cost for the 52 households in this group with positive collection costs was 1215 NPR. Many households in this group also incur pumping costs (456 NPR, $N = 76$) and storing costs (422 NPR, $N = 63$). These households spend a similar amount buying (475 NPR, $N = 60$) and treating water (116 NPR, $N = 50$).

For the 600 households with a PWC but no private well, most incur costs storing (267 NPR, $N = 554$), buying (493 NPR, $N = 412$), and pumping (93 NPR, $N = 415$). Over half also participate in treating (136 NPR, $N = 383$) and collecting (404 NPR, $N = 252$). Collecting costs are less than those of an average household without a PWC.

The 738 households with both a PWC and private well incur large costs pumping (369 NPR, $N = 709$) storing (488 NPR, $N = 704$), and purchasing (623 NPR, $N = 444$). The costs of treating are smaller (191 NPR, $N = 599$). Only a small portion of these households incurs costs collecting water (364 NPR, $N = 65$).

Figure 3 summarizes the composition of coping costs for households in each of the four groups. It shows the average cost for a household for each of the five coping strategies. Because not all households use all coping methods, the composition of coping costs for each of the four groups should not be interpreted as representative of an average household. We see that unconnected households incur higher coping costs

Table 5. Descriptive Statistics

Variable Name	Description	2001					2014					Difference				
		Mean	10p	Median	90p	N	Mean	10p	Median	90p	N	Mean	10p	Median	90p	N
<i>Coping</i>	Total coping costs, 2014 NPR	476	48	321	978	927	1,198	201	895	2,515	927	722	−238	491	2,077	927
<i>Respondent_edu</i>	Respondent education, in years	8	0	10	13	927	8	0	9	16	927	0	−10	0	7	927
<i>Respondent_hhhead</i>	Respondent is household head (1=yes, 0=no)	0.4	0	0	1	927										
<i>Respondent_male</i>	Respondent is male (1=yes, 0=no)	0.6	0	1	1	927	0.6	0	1	1	927	0.4	0.0	0.0	1.0	927
<i>Household_size</i>	Household size	8.2	5	8	12	927	5.1	3	5	8	927	−3.1	−7.0	−3.0	0.0	927
<i>Income</i>	Income, 2014 NPR/month	381,027	11,482	25,515	67,616	927	57,452	18,000	43,000	100,000	927	19,425	−23,376	14,485	64,639	927
<i>Uses_PWC</i>	Uses a private water connection	1	0	1	1	927	0.7	0	1	1	927					
<i>Diff_PWC</i>	Change in connection status (1=change, 0=no change)											0.2	0.0	0.0	1.0	927
<i>Diff_PWCXGain_PWC</i>	Interaction between change in connection status and gaining a PWC											0.1	0.0	0.0	1.0	927
<i>Uses_privatewell</i>	Uses a private well	0.3	0	0	1	927	0.4	0	0	1	927					
<i>Diff_well</i>	Change in private well usage (1=change, 0=no change)											0.2	0.0	0.0	1.0	927
<i>Diff_wellXGain_well</i>	Interaction between change in private well usage and gaining a private well											0.2	0.0	0.0	1.0	927
<i>N_sources</i>	Number of sources used	2.1	1	2	3	927	2.6	1	2	4	927	0.5	−1.0	0.0	2.0	927
<i>Service_hrs</i>	Hours of service from PWC	1.1	0	0.6	2.5	927	1.4	0.5	1.0	2.7	927	0.3	−1.5	0.7	1.8	927
<i>Taste_wet</i>	Perception about taste of piped water in the wet season, 1=excellent to 4=poor	3.5	3	4	4	927	2.9	2	3	4	927	−0.6	−2.0	−1.0	1.0	927
<i>Taste_dry</i>	Perception about taste of piped water in the dry season, 1=excellent to 4=poor	2.8	2	3	3	927	2.8	2	3	4	927	0.0	−1.0	0.0	1.0	927
<i>Color_wet</i>	Perception about color of piped water in the wet season, 1=very clean to 4=poor very dirty	2.9	2	3	4	927	2.4	2	2	3	927	−0.6	−1.0	−1.0	0.0	927
<i>Color_dry</i>	Perception about color of piped water in the dry season, 1=very clean to 4=very dirty	2.2	2	2	3	927	2.2	2	2	3	927	0.0	−1.0	0.0	1.0	927
<i>Health_wet</i>	Perception about health risks of piped water in the wet season, 1=no risk to 1=4 serious risk	2.0	1	2	3	927	2.2	1	2	4	927	0.2	−1.0	0.0	2.0	927
<i>Health_dry</i>	Perception about health risks of piped water in the dry season, 1=no risk to 1=4 serious risk	2.4	2	2	3	927	2.3	1	2	4	927	−0.1	−1.0	0.0	1.0	927
<i>Reliab_wet</i>	Perception about reliability of piped water in the wet season, 1=very regular to 4=unreliable	2.7	2	3	3	927	2.3	2	2	3	927	−0.4	−1.0	0.0	1.0	927
<i>Reliab_dry</i>	Perception about reliability of piped water in the dry season, 1=very regular to 4=unreliable	3.1	2	3	4	927	2.9	2	3	4	927	−0.2	−1.0	0.0	1.0	927
<i>Concern_water</i>	Belief that water issues are the most important environmental problem	0.8	0	1	1	927	0.8	0	1	1	927					
<i>Diff_water</i>	Change in beliefs about importance of water issues											0.3	0.0	0.0	1.0	927
<i>Diff_waterX Become_water</i>	Interaction between change in beliefs and changing beliefs about water issues from not the most important to the most important environmental problem.											0.2	0.0	0.0	1.0	927

than connected households, which is primarily due to greater time spent collecting water. Additionally, households with private wells incur higher coping costs because they spend more on building and operating pumps and wells. Storage costs are highest for households with both a PWC and a private well, slightly less for households with only a PWC or only a private well, and the least for households without either a private well or a private connection. Purchases from water vendors are similar across all four household types. Treatment costs for households with both a PWC and a private well are higher than those for the other three household types.

Figure 3. Composition of coping costs, by household type (2014).

Table 4 also presents a comparison of the estimates of total household coping costs in 2001 and 2014. Average household coping costs have more than doubled in real terms over the period from 2001 to 2014, from 524 NPR to 1206 NPR (both in 2014 NPR). Because real household incomes have increased about 36%, coping costs for the average household have increased as a proportion of total income (from about 2% to 3%).

Table 4 also presents a summary of household-level changes in real coping costs by coping cost

component and household type. Households have on average increased their coping costs by 682 NPR per month. The only component of coping costs that decreased from 2001 to 2014 was the time spent collecting water (by an average of 121 NPR per month). Pumping costs increased by 233 NPR; storage costs increased by 272 NPR; and expenditures on water vendors increased by 472 NPR. Treatment costs stayed essentially the same in real terms, increasing by only 13 NPR.

Households without PWCs in 2014 that chose to collect water in either 2001 or 2014 experienced large increases in collection costs, while connected households experienced decreases in collection costs. Households with private wells had large increases in pumping costs. Some households without private wells in 2014 still incurred costs for pumping water from private connections to both overhead and in-ground storage tanks, but the increases in pumping costs were smaller than those for households with private wells. Households without either a PWC or a private well also experienced changes in coping costs similar to households in the other three groups—large increases in purchase costs and smaller increases in storing and treating. Households without a private water connection but with a private well experienced the largest increase in coping costs—1108 NPR per month. This was due to increases in collection costs (465 NPR per month), pumping costs (348 NPR per month), and purchases from vendors (416 NPR per month). There was, however, a small decrease in treatment costs. Households with a private water connection and no private well experienced a smaller increase in coping costs of 488 NPR, due mostly to the large increase in purchases from vendors, offset by a decrease in collecting costs. Households with both a PWC and a private well also experienced an increase in coping costs of 762 NPR per month. Despite a large decrease in collection costs for over half of these households, there were large increases in pumping and storing costs for nearly the entire subsample. There was also an increase in purchasing costs for over half of the households with both a PWC and a private well.

Figure 4 shows the composition of coping costs by income decile for 2001 and 2014, respectively. Two major shifts occurred over the period. First, the costs of time spent collecting water declined across most income deciles (all except the third and fourth deciles) because fewer households were collecting water from sources outside their homes, particularly in the higher income deciles. The reduction in the coping costs associated with time spent collecting water is most dramatic for low-income households. In 2001, over 75% of the total coping costs of households in the poorest decile was the value of time spent collecting water; in 2014, this percentage was only 20%. By 2014, households in the richest three income deciles effectively stopped spending time collecting water from outside the home.

Second, monetary payments to water vendors rose dramatically. These monetary expenditures were for water purchases from both tanker trucks and bottled water vendors. In 2014, both poor and rich households were spending much more on vended water than in 2001.

Figure 4. Composition of coping costs, by income decile (in 2001, 41 of 48 households who purchased from vendors bought from tankers, and expenditures were not recorded).

2001, households with private connections paid about 133% more in monthly coping costs than their water bill. By 2014, monthly coping costs were approximately four times greater than their water bill.

Figure 6 illustrates the total monthly water supply costs for each of the four types of households in our typology. Figure 6 displays the total monthly costs as the sum of three cost categories: (1) the costs of publicly supplied (KUKL) water that are not paid by households with private connections (effectively the subsidies provided by government and donors); (2) the portion of the costs of the public supply paid by households through their water bill; and (3) the private coping costs households pay in addition to the costs of the water supplied by the public system. The total cost of water provided by KUKL (capital plus operation and maintenance) is assumed to be 95 NPR (US\$1) per cubic meter. Figure 6 shows that private household coping costs make up the largest overall portion of the total costs of supplying water to households. The total costs to

Figure 5. Distribution of household coping costs by income, 2001 and 2014.

To better understand the distribution of coping costs across income, Figure 5 presents the percentage of total coping costs on the vertical axis versus the percentage of households ranked from lowest to highest income on the horizontal axis in both 2001 and 2014. Figure 5 shows that the distribution of coping costs by household income has not changed much between 2001 and 2014. Households' coping costs were widely distributed throughout all income groups in the population in both 2001 and 2014. The coping costs per cubic meter average 198 NPR (US\$2) in 2014, and there is little difference in coping costs per cubic meter between the poor and wealthy income groups.

In 2001, average water bills for households with private connections were 152 NPR (in 2001 NPR) (387 NPR in 2014 NPR). By 2014, these had increased to only 218 NPR, a 44% decrease in real terms. In

Figure 6. Composition of total costs of water supply services, by household type (2014).

households with both PWCs and private wells, including the subsidies these households receive from taxpayers and donors, is the highest of the four groups.

7. Explaining Differences in Total Household Coping Costs (2001 Versus 2014)

Table 5 presents the summary statistics for the variables used in the regression analysis. Table 6 presents the results for three different specifications of the model described in section 4, estimated using only the matched households. For each of the three specifications, we first run the regression with only the arguably exogenous variables (household characteristics) and then with the entire set of independent variables of interest. Models 1 and 2 use differences between 2001 and 2014 for all variables and are our preferred specifications because they control for time invariant factors. We run the same model using only the 2001 data (Models 3 and 4) and then with the 2014 data (Models 5 and 6). We discuss the results from Models 1 and 2 here (results of Models 3–6 are discussed in the Appendix).

Additionally, the Breusch-Pagan test for heteroskedasticity is conducted for all the models. The null hypothesis of homoskedasticity is rejected for all models; therefore, *White's* [1980] heteroskedastic-consistent covariance matrix estimator is used to correct the estimated standard errors for an unknown form of heteroskedasticity.

Model 1 focuses on the effects of four arguably exogenous household characteristics—respondent education, gender, household size, and income. Respondent education and gender are not significant. However, the coefficients on household size and income are positive and statistically significant, indicating that households with higher incomes and more members have higher coping costs.

In Model 2, income and household size effects are robust to the addition of variables in the full model. The coefficient on gaining a private water connection is negative and significant at the 1% level, indicating that obtaining a private water connection is associated with decreases in coping costs. The coefficient on having a private well is not statistically significant, nor is the coefficient on having both a private well and private water connection. The number of sources used has a positive and statistically significant association with household coping costs.

The magnitude of the effect of gaining a private water connection is the sum of the coefficients on *Diff_PWC* and *Diff_PWCXGain_PWC*, which is 287. To illustrate this effect, we can forecast the decrease in coping costs that households without either a private water connection or a private well would experience if they were to obtain a private connection. The predicted change in coping costs for a household that does not have a PWC in 2001 and is still unconnected in 2014 is estimated to be 732 NPR. The predicted change in coping costs for households that gain a private water connection is 445 NPR. This difference of 287 NPR is the decrease in coping costs attributable to obtaining a private water connection.

Almost all perceptions about the quality of piped water (in terms of taste, color, health risks, and reliability) do not have robust, statistically significant associations with coping costs. Only poor reliability in the dry

Table 6. Regression Results^a

Variables	(1) diff_coping_adj	(2) diff_coping_adj	(3) coping2001_adj	(4) coping2001_adj	(5) coping_2014	(6) coping_2014
<i>Respondent_edu</i>	8.890 (6.249)	7.325 (6.110)	7.061 (6.307)	10.33 (6.308)	27.79 ^d (7.460)	27.92 ^d (6.877)
<i>Respondent_male</i>	−104.5 (80.11)	−130.0 ^b (78.50)	−20.28 (50.00)	−38.14 (49.79)	−38.77 (68.11)	35.11 (64.58)
<i>Household_size</i>	36.70 ^d (11.23)	23.14 ^c (10.72)	−3.019 (7.293)	−5.296 (7.084)	52.68 ^d (16.94)	32.76 ^c (16.43)
<i>Income</i>	0.902 ^b (0.508)	1.213 ^c (0.487)	1.465 ^c (0.596)	1.729 ^d (0.636)	0.833 (0.587)	1.141 ^b (0.622)
<i>Uses_PWC</i>				−252.1 ^d (92.19)		−110.3 (93.38)
<i>Diff_PWC</i>		296.7 ^c (122.4)				
<i>Diff_PWCXGain_PWC</i>		−583.7 ^d (181.1)				
<i>Uses_privatelywell</i>				−93.05 (107.3)		205.3 (149.5)
<i>Diff_well</i>		20.48 (159.0)				
<i>Diff_wellXGain_well</i>		−106.1 (166.4)				
<i>Uses_PWCXUses_privatelywell</i>				−66.34 (111.7)		−25.32 (157.9)
<i>Gain_both</i>		906.4 (585.7)				
<i>N_sources</i>		288.9 ^d (30.26)		−59.62 (43.31)		287.6 ^d (34.97)
<i>Service_hrs</i>		7.315 (13.41)		19.91 (43.49)		58.82 ^c (26.13)
<i>Taste_wet</i>		−33.01 (54.06)		−104.5 ^b (56.95)		46.24 (85.56)
<i>Taste_dry</i>		69.37 (58.76)		−63.43 (55.04)		−58.40 (90.15)
<i>Color_wet</i>		17.74 (67.48)		−33.51 (51.33)		66.63 (79.17)
<i>Color_dry</i>		−24.53 (76.11)		−10.07 (47.76)		90.68 (85.91)
<i>Health_wet</i>		52.02 (61.35)		17.56 (53.28)		−23.97 (90.38)
<i>Health_dry</i>		14.76 (57.34)		75.97 ^b (42.30)		172.2 ^b (87.99)
<i>Reliab_wet</i>		−69.24 (49.58)		−74.13 (47.24)		−75.95 (57.96)
<i>Reliab_dry</i>		106.2 ^c (50.18)		77.33 ^b (42.44)		108.8 ^c (52.20)
<i>Concern_water</i>				−72.27 (47.95)		−44.96 (74.27)
<i>Diff_water</i>		83.94 (109.9)				
<i>Diff_waterXBecome_water</i>		−266.9 ^b (138.3)				
Constant	1008 ^d (103.7)	712.8 ^d (125.0)	446.1 ^d (103.2)	513.7 ^b (289.5)	865.3 ^d (134.6)	−837.0 ^d (321.4)
Observations	927	927	927	927	927	927
R-squared	0.068	0.202	0.042	0.204	0.119	0.246

^aRobust standard errors in parentheses.

^b $p < 0.1$.

^c $p < 0.05$.

^d $p < 0.01$.

season is significantly associated with higher coping costs. This is surprising, given findings from other studies in the literature, which highlight the importance of perceptions about the desirable qualities of water supply [Um et al., 2002; Abrahams et al., 2000; Katuwal and Bohara, 2011]. We would expect, given our larger sample size, to have enough power to detect an effect if one existed.

Based on the results of Model 2, we conclude that household income, having a private connection, household size, number of sources used, and perceived (un)reliability of piped water in the dry season have the strongest associations with coping costs. The positive association of household income and coping costs suggests that improved water service is a normal good, and demand increases with income. The negative association of having a private water connection and coping costs suggests that having a heavily subsidized water supply from the piped network is valuable to a household, even if the service is unreliable and the quality of the water provided is poor. Additionally, having a larger household, using more sources, and a PWC that is perceived to be unreliable are associated with higher coping costs.

8. Discussion

Our resurvey of 1500 households first interviewed in 2001 has enabled us to better understand how households in Kathmandu have managed to cope with an increasing water shortage and lack of investment in public water supply infrastructure. After 2001, private water vendors have stepped into the water economy of Kathmandu and have provided a significant portion of the increased investment and water supplies that the public desperately needed. In 2001, only 71 out of 1500 households in our sample purchased water from tanker truck vendors or from bottled water vendors. In 2014, every single household in our sample (except one) reported that they purchased water from vendors (either tanker truck or bottled water) at some time during the year. Additionally, households have made private investments in water storage and

private wells. Only households with both a private connection and a private well (49% of sample households) managed to obtain an arguably sufficient quantity of water (94 lpcd). Households without either a private connection or a private well used only 35 lpcd.

Real coping costs have more than doubled between 2001 and 2014, to an average of US\$12 per household per month. The burden of coping costs falls evenly throughout the income distribution. The coping costs per cubic meter are also not significantly different across income groups. Rising household incomes over the period from 2001 to 2014 allowed households to install more storage tanks, drill more private wells, and pay tanker truck and bottled vendors for water, resulting in increased coping costs for dealing with the poor quality, unreliable supplies from the public system. These private investments have resulted in a decline in the time households spend collecting water from outside the home. Despite the increase in household incomes, households still experienced an increase in the percentage of their income spent coping with poor quality, unreliable public water supplies (from 2% to 3%).

Households with private connections incurred coping costs of US\$12.49 per month (1,187 NPR), four times higher than their water bills (US\$3.03 or 288 NPR per month). Even the poor quality services of the existing PWCs are more valuable to households than the water bills that they pay. Our regression analysis shows that gaining a PWC is associated with a decrease in coping costs. Currently, household perceptions about the taste, color, and health risks of the water from piped connections do not have significant relationships with coping costs. Only poor reliability has a significant association with higher coping costs, suggesting that this is the service attribute of piped water services that households care most about.

As shown in the theoretical framework, our coping cost estimates are simply one component of household willingness to pay for improved water quality and are only suggestive of the long-run demand for improved public water supplies. For example, our coping cost estimates will not capture the anxiety and stress households experience as they struggle with the uncertainty associated with accessing water from multiple sources, especially during the dry season. However, because coping costs are a significant portion of household expenditures, there is potential for large water supply improvement projects, such as the MWSP, to increase household welfare. The decreases in coping costs that would result from increased investments in public water infrastructure would be largest for households that obtain a new PWC, have less reliable PWCs now, and are able to decrease the number of sources used. These households are thus the most likely to experience increases in household welfare when the public water supply system in Kathmandu is improved. However, because our coping cost estimates cannot be interpreted as lower bound estimates of household willingness to pay for improved piped services in the short run, we are unable to predict the magnitude of the welfare improvements that will accrue to households that have made substantial capital investments in private wells and pumps, storage tanks, and in-house water treatment systems.

Our results have implications for the reform of water tariffs in Kathmandu. The completion of a large water supply improvement project, the MWSP, represents a unique opportunity to reform municipal water tariffs and put KUKL on a sounder financial footing. An increase in municipal water tariffs for households that experience an improvement in the quality and reliability of piped water services will allow the water utility to share the economic and financial benefits that will accrue to households. If there is not a substantial tariff increase when the MWSP is completed and municipal water services improve, households will grow accustomed to high quality services at very low prices, and it may be even harder to reset tariffs in the future.

The redesign of water tariffs will remain challenging. On one hand, the significant increase in water supply after the completion of MWSP should allow the water utility to capture some of the savings in coping costs that some households will experience, especially potential cost savings resulting from reduced purchases of vended water. On the other hand, we emphasize that the design of the new tariffs will need to consider the competition from the private vending sector and from the fact that many households have already incurred the costs of installing private wells.

Both vendors and private wells are alternative water sources for households and represent competition for the water supplied by public water utility from public taps and private connections. However, from the households' perspective, the cost and quality attributes of water supplied by vendors and private

wells are quite different. Water from tankers and “jar” vendors is of relatively high quality. Marginal costs are high, but investment costs are minimal. Households can easily stop purchases of water from vendors.

However, the use of water from a private well requires substantial upfront investment costs and marginal costs, once the well and pump are installed, are low (mainly electricity costs for running the pump and minor repairs). However, there is an additional dimension to the economics of private wells. As more and more households have drilled wells, the groundwater table in Kathmandu has been falling. This means that households with private wells may find that they can no longer easily reach the groundwater, i.e., their well needs to be deepened to reach the falling groundwater table, incurring additional capital costs.

Finally, it is important to emphasize that although coping costs are related to the benefits of the MWSP, the objective of this paper has not been to reanalyze the costs and benefits of the MWSP, or to consider possible solutions to water scarcity in the Kathmandu Valley in addition to interbasin transfer. For example, conceptually the recycling of wastewater is an alternative water “tap” that could be used instead of an interbasin transfer. Singapore provides a good example of how this can be done. However, the capital costs and technical capacity required to actually implement this solution are out of reach in Kathmandu. Indeed, to the best of our knowledge, recycling wastewater for potable use has not been accomplished in any low-income country, certainly not any country with GDP per capita as low as Nepal.

Appendix: Additional Discussion of Regression Results Presented in Table 6

First, we examine the results from Models 3 and 4, for 2001. In Model 3, household income has a positive, statistically significant coefficient, indicating that households with higher incomes have higher coping costs. However, respondent education, gender, and household size do not have statistically significant coefficients. In Model 4, after adding additional explanatory variables, the coefficient on household income remains significant and positive. Using a private water connection has a statistically significant, negative coefficient. In 2001 households that used a private water connection, on average and all else equal, had coping costs that were 252 NPR per month lower than households without private connections. For households using a private well, the coefficient is negative but not statistically significant. Most of the coefficients on the variable describing a household’s perceptions of piped water quality are not statistically significant. The only statistically significant coefficients are for the taste of the PWC water in the wet season (negative), health in the dry season (positive), and the reliability of the PWC during the dry season (positive). The explanatory variable describing a household’s concern about water issues with respect to other environmental policies does not have a statistically significant association with coping costs.

The results for Model 5 (2014 data with only the exogenous household characteristics) are different compared to those for Model 3. The coefficients on respondent education and household size are significant and positive, while the coefficients on respondent gender and income are not significant. The results for Model 6 (2014 data with the full set of explanatory variables) show that the coefficients on respondent education and household size remain significant and positive. The coefficient on income becomes positive, as for the 2001 models, and significant at the 10% level. The results for model 6 also differ from model 4 for a household’s use of a private well and private water connection. In model 6, the coefficient on using a PWC is not significant, while it is significant at the 1% level in model 4. Having and using a private water connection in 2014 is not significantly related to a decrease in coping costs. Additionally, the coefficient on the use of a private well, while not significant, changes from negative (in model 4) to positive (in model 6). The coefficient on number of sources used is positive and significant at the 1% level. For the average household, increasing the number of sources used by one is associated with an increase of 288 NPR per month.

In Model 6, the coefficients on households reporting negative perceptions about health and reliability in the dry season are positive and significant at the 5% level. This implies that as households hold a more negative perception about the health effects and reliability of piped water, coping costs are higher. The coefficient on another measure of reliability, the number of hours of service from the PWC each month has a positive and significant (at the 5% level) coefficient. This is odd because higher levels of service are associated with higher coping costs.

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References

- Abdalla, C. (1990), Measuring economic losses from groundwater contamination: An investigation of household avoidance costs, *Water Resour. Bull.*, 26(3), 451–463, doi:10.1111/j.1752-1688.1990.tb01384.x.
- Abrahams, N. A., B. J. Hubbell, and J. L. Jordan (2000), Joint production and averting expenditure measures of willingness to pay: Do water expenditures really measure avoidance costs?, *Am. J. Agric. Econ.*, 82, 427–437, doi:10.1111/0002-9092.00036.
- Ashraf, N., J. Berry, and J. M. Shapiro (2010), Can higher prices stimulate product use? Evidence from a field experiment in Zambia, *Am. Econ. Rev.*, 100, 2383–2413, doi:10.1257/aer.100.5.2383.
- Asian Development Bank (ADB) (2008), *Nepal: Melamchi Water Supply Project and Kathmandu Valley Water Services Sector Development Program, Major Change in Scope and Implementation Arrangements*, Manila.
- Asthana, A. (1997), Where the water is free but the buckets are empty: Demand analysis of drinking water in rural India, *Open Econ. Rev.*, 8(2), 139–149.
- Babbie, E. (1990), *Survey Research Methods*, Wadsworth, Stamford, Conn.
- Bartik, T. J. (1988), Measuring the benefits of amenity improvements in hedonic price models, *Land Econ.*, 64(2), 172–183.
- Bhandari, T. M. (2014), *Current Status of Water Supply in Kathmandu Valley*, presentation at Kathmandu Upatyaka Khanepani Limited, Kathmandu.
- Binnie and Partners (1973), Master plan for the water supply and sewerage of greater Kathmandu and Bhaktapur, *U. N. Dev. Programme (Spec. Fund) Proj. – Nepal 0025*, World Health Organ, Kathmandu.
- Binnie and Partners (1988), Water supply for Kathmandu-Lalitpur from outside the valley—Pre-feasibility study, final report, London.
- Boardman, A., D. Greenberg, A. Vining, and D. Weimer (2010), *Cost-Benefit Analysis: Concepts and Practices*, 4th ed., Prentice Hall, Upper Saddle River, N. J.
- Collins, A., and S. Steinback (1993), Rural household response to water contamination in West Virginia, *Water Resour. Bull.*, 29(2), 199–209, doi:10.1111/j.1752-1688.1993.tb03201.x.
- Cook, J., P. Kimuyu, A. Blum, and J. Gatua (2016a), A simple stated preference tool for estimating the value of travel time in rural Africa, *J. Benefit Cost Anal.*, 7(2), 221–247, doi:10.1017/bca.2016.13.
- Cook, J., P. Kimuyu, and D. Whittington (2016b), The costs of coping with poor water supply in rural Kenya, *Water Resour. Res.*, 52, 841–859, doi:10.1002/2015WR017468.
- Cropper, M. L., and W. E. Oates (1992), Environmental economics: A survey, *J. Econ. Lit.*, 30(2), 675–740.
- DeVoto, F., E. Duflo, P. Dupas, W. Parienté, and V. Pons (2012), Happiness on tap: Piped water adoption in urban Morocco, *Am. Econ. J. Econ. Policy*, 4(4), 68–99.
- Domenech, L., H. March, and D. Sauri (2013), Contesting large-scale water supply projects at both ends of the pipe in Kathmandu and Melamchi Valleys, Nepal, *Geoforum*, 47, 22–31, doi:10.1016/j.geoforum.2013.02.002.
- Gurung, Y., J. Zhao, K. C. Bal Kumar, X. Wu, B. Suwal, and D. Whittington (2017), Household Water Supply and Coping Costs in Kathmandu Valley, 2001 and 2014, *Hydroshare*, doi:10.4211/hs.11c23c95c4e9496190c1e3d2c74407a9.
- International Monetary Fund (2015), *Consumer Price Index Dataset*, Washington, D. C.
- Jalan, J., and S. Somanathan (2008), The importance of being informed: Experimental evidence on demand for environmental quality, *J. Dev. Econ.*, 87, 14–28, doi:10.1016/j.jdeveco.2007.10.002.
- Jesso, K. (2013), Improved source, improved quality? Demand for drinking water quality in rural India, *J. Environ. Econ. Manage.*, 66, 460–475, doi:10.1016/j.jjeem.2013.05.001.
- Kathmandu Upatyaka Khanepani Limited (KUKL) (2014), *Present Situation of Water Distribution in Kathmandu Valley*, Presentation in Kathmandu.
- Kathmandu Upatyaka Khanepani Limited (2015), *Aid by Third Countries or International Organizations in the Related Field*, Kathmandu.
- Katuwal, H., and A. K. Bohara (2011), Coping with poor water supplies: Empirical evidence from Kathmandu, Nepal, *J. Water Health*, 9(1), 143–158, doi:10.2166/wh.2010.151.
- Kremer, M., J. Leino, E. Miguel, and A. P. Zwane (2011), Spring cleaning: Rural water impacts, valuation, and property rights institutions, *Q. J. Econ.*, 126, 145–205, doi:10.3386/w15280.
- Larson, B. A., and E. D. Gnedenko (1999), Avoiding health risks from drinking water in Moscow: An empirical analysis, *Environ. Dev. Econ.*, 4, 565–581.
- Laughland, A. S., L. M. Musser, W. N. Musser, and J. S. Shortle (1993), The opportunity cost of time and averting expenditures for safe drinking water, *Water Resour. Bull.*, 29(2), 291–299.
- Madajewicz, M., A. Pfaff, A. van Geen, J. Graziano, I. Hussein, H. Momotaj, R. Sylvi, and H. Ahsan (2007), Can information alone change behavior? Arsenic contamination of groundwater in Bangladesh, *J. Dev. Econ.*, 84(2), 731–754.
- Mäler, K.-G. (1974), *Environmental Economics: A Theoretical Inquiry*, Johns Hopkins Univ. Press, Baltimore, Md.
- Mäler, K.-G., and R. E. Wyzga (1976), *Economic Measurement of Environmental Damage: A Technical Handbook*, Org. for Econ. Coop. and Dev., Paris.
- McConnell, K. E., and M. A. Rosado (2000), Valuing discrete improvements in drinking water quality through revealed preferences, *Water Resour. Res.*, 36(6), 1575–1582, doi:10.1029/2000WR900043.
- Muzzini, E., and G. Aparicio (2013), *Urban Growth and Spatial Transition in Nepal: An Initial Assessment*, Directions in Development, World Bank, Washington, D. C.
- Pandey, V. P., S. Shrestha, and F. Kazama (2012), Groundwater in the Kathmandu Valley: Development dynamics, consequences and prospects for sustainable management, *Eur. Water*, 37, 3–14.
- Pant, D., M. Bhattarai, and G. Basnet (2008), A case study of the Melamchi Water Supply Project in Nepal, *CAPRI Work. Pap.* 78, Int. Food Policy Res. Inst., Washington, D. C.
- Pattanayak, S., J.-C. Yang, D. Whittington, and B. Kumar (2005), Coping with unreliable public water supplies: Averting expenditures by households in Kathmandu, Nepal, *Water Resour. Res.*, 41, W02012, doi:10.1029/2003WR002443.
- Pattanayak, S. K., C. Poulos, J.-C. Yang, and S. R. Patil (2013), *How Valuable are Environmental Health Interventions? Evidence From a Quasi-Experimental Evaluation of Community Water Projects*, enGender Impact: the World Bank's Gender Impact Evaluation Database, World Bank, Washington, D. C.
- Reed, B., and B. Reed (2013), How much water is needed in emergencies, *Tech. Note 9 on Drinking-Water, Sanitation, and Hygiene in Emergencies*, WEDC for WHO, Leicestershire, U. K.
- SILT Consultants and Development Research and Training Center (1999), Consumer survey for project on urban water supply and sanitation rehabilitation, technical report, Kathmandu.

- Snowy Mountain Engineering Consultants (1992), Greater Kathmandu Water Supply Project, final report, Report in Association with CEMAT Consultants.
- Subedi, B. P. (2014), *Urbanization in Nepal: Spatial Pattern, Social Demography and Development, Population Monograph: Economic Demography*, vol. III, chap. 4, pp. 95–154, Census Bur. of Nepal, Kathmandu.
- Suwal, B. R. (2014), *Internal Migration in Nepal. Population Monograph: Economic Demography*, vol. I, chap. 10, pp. 241–284, Cent. Bur. of Stat., Gov. of Nepal, Kathmandu.
- Swyngedouw, E. (2004), *Social Power and the Urbanization of Water*, Oxford Univ. Press, Oxford, U. K.
- Tiwari, D. (2000), Users' willingness to pay for averting environmental health risks and implications for alternative policy measures for improving water supply facilities in Kathmandu Valley, final report, Dep. of Water Supply and Sewerage, Kathmandu.
- Um, M.-J., S.-J. Kwak, and T.-Y. Kim (2002), Estimating willingness to pay for improved drinking water quality using averting behavior method with perception measure, *Environ. Resour. Econ.*, 21(3), 287–302, doi:10.1023/A:1014537330423.
- Vásquez, W. F. (2012), Reliability perceptions and water storage expenditures: Evidence from Nicaragua, *Water Resour. Res.*, 48, W10547, doi:10.1029/2011WR011024.
- Vásquez, W. F., P. Mozumder, J. Hernández-Arce, and R. P. Berrens (2009), Willingness to pay for safe drinking water: Evidence from Parral, Mexico, *J. Environ. Manage.*, 90, 3391–3400, doi:10.1016/j.jenvman.2009.05.009.
- Von Wartburg, M., and W. Waters II (2004), Congestion externalities and the value of travel time savings, in *Towards Estimating the Social and Environmental Costs of Transportation in Canada: A Report for Transport Canada*, edited by A. Zhang et al., chap. 2, pp. 60–152, Cent. for Transp. Stud., Univ. of B. C., Vancouver, Canada.
- White, H. (1980), A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity, *Econometrica*, 48(4), 817–838.
- Whittington, D., X. Mu, and R. Roche (1990), Calculating the value of time spent collecting water: Some estimates for Ukunda, Kenya, *World Dev.*, 18(2), 269–280.
- Whittington, D., S. Pattanayak, J.-C. Yang, and B. Kumar (2002), Household demand for improved piped water services in Kathmandu, Nepal, *Water Policy*, 4(6), 531–556.
- Whittington, D., D. T. Lauria, V. Prabhu, and J. Cook (2004), An economic reappraisal of the Melamchi Water Supply Project, Kathmandu, Nepal, *Port. J. Econ.*, 3(2), 157–178, doi:10.1007/s10258-004-0032-0.
- Whittington, D., W. M. Hanemann, C. Sadoff, and M. Jeuland (2009), The challenge of improving water and sanitation services in less developed countries, *Found. Trends Microecon.*, 4(6–7), 469–609.