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Key Points:

- Time spent collecting water comprises the majority of coping costs
- Median total coping costs are US$20 per month, higher than urban water bills
- Coping costs are >10% of monthly cash income in over one half of households

Supporting Information:

- Supporting Information S1

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The costs of coping with poor water supply in rural Kenya

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Abstract As the disease burden of poor access to water and sanitation declines around the world, the nonhealth benefits––mainly the time burden of water collection – will likely grow in importance in sector funding decisions and investment analyses. We measure the coping costs incurred by households in one area of rural Kenya. Sixty percent of the 387 households interviewed were collecting water outside the home, and household members were spending an average of 2–3 h doing so per day. We value these time costs using an individual-level value of travel time estimate based on a stated preference experiment. We compare these results to estimates obtained assuming that the value of time saved is a fraction of unskilled wage rates. Coping cost estimates also include capital costs for storage and rainwater collection, money paid either to water vendors or at sources that charge volumetrically, costs of treating diarrhea cases, and expenditures on drinking water treatment (primarily boiling in our site). Median total coping costs per month are approximately US$20 per month, higher than average household water bills in many utilities in the United States, or 12% of reported monthly cash income. We estimate that coping costs are greater than 10% of income for over half of households in our sample. They are higher among larger and wealthier households, and households whose primary source is not at home. Even households with unprotected private wells or connections to an intermittent piped network spend money on water storage containers and on treating water they recognize as unsafe.

1. Introduction

Many people are not aware that childhood mortality rates are declining in developing countries, and that this decline is accelerating. The global decline from 1990 to 2010 is 2.1% per year for neonatal mortality, 2.3% for postneonatal mortality, and 2.2% for childhood mortality [*Rajaratnam et al.*, 2010]. Across 21 regions of the world, rates of neonatal, postneonatal, and childhood mortality are declining, and in 13 regions of the world, including all regions in sub-Saharan Africa, and there is evidence of accelerating declines from 2000 to 2010 compared with 1990–2000. Mortality due to poor water and sanitation conditions is also falling as improved water and sanitation coverage increases [*Jeuland et al.*, 2013]

These declines in WASH-related mortality have important implications for the economic appraisal of investments in improved water and sanitation services, especially piped network services [*Global Water Partnership*, 2015]. The economic benefits of improved water services consist of both health and nonhealth benefits. Estimates of the health benefits include how people value reductions in both their mortality risk and their nonfatal disease burden (morbidity). The nonhealth benefits include time savings from not having to walk to collect water from sources outside the home, reductions in averting or defensive expenditures, and aesthetic and lifestyle benefits. To the extent that baseline childhood mortality rates are lower, the health benefits of improved water and sanitation services will be lower, and the relative importance of nonhealth benefits (i.e., as a proportion of the total benefits) will increase.

This paper provides estimates of the coping costs that households incur to obtain water supplies in one rural area in Kenya. We show that household coping costs are substantial. Although we only measure one component of health benefits (reductions in diarrhea treatment costs), our results suggest that most of the benefits that would result from improved piped services in the home would be time savings. We also show that there is great heterogeneity in coping costs across households, both due to differences in the amount of time spent collecting water and the value of time saved. Rather than rely solely on assumptions about the value of travel time based on a fraction of wages, we use values predicted from a latent class model estimated with data obtained from a companion stated preference experiment [*Cook et al*., 2015]. Because enumerators recorded GIS locations of houses and water sources, we are also able to test the sensitivity of estimates of collection time estimates based on reported and observed distances, the first such comparison we are aware of in the coping cost literature.

In the first section of the paper we provide a theoretical framework of household choices regarding water and health interventions that illustrates the different components of the total economic benefits of such investments. We use this theoretical framework to illustrate the coping cost component of the total economic benefits from a water intervention. The second section describes our study site in Kenya, the fieldwork and data collection activities, and the demographics of households in the study area. The third section describes households' existing water supply situations. In the fourth section we present our procedures for calculating households coping costs and the assumptions we make. The fifth section presents the results and in the sixth section we offer some concluding observations.

2. Theory and Existing Literature

To better understand households' behavioral decisions around coping with unimproved water supply, we begin with a household production function approach, drawing heavily from the one described in *Pattanayak et al*. [2005] and *Pattanayak and Pfaff* [2009]. The goal is two-fold: to illustrate how coping costs are related to the total economic benefits of "improved" water supply, and to generate some simple theoretical predictions for how coping costs may be related to characteristics of households. We conclude this section with a discussion of other empirical coping cost estimates for water supply.

A household production function approach treats a household as combining exogenous and endogenous inputs into some output or good that households value, conditioned on that household's tastes and preferences. An improved water supply––defined here simply as one that provides water reliably, of potable quality, and of sufficient quantity to meet basic household needs like drinking, bathing, cooking, and washing around the house––is not that output. Rather, households value the good health and other amenities that water supply provides, namely, quenched thirst, clean homes and clothes, and perhaps productive and attractive kitchen gardens. These services provide households utility (equation (1)), which they maximize given their limited total time resources (equation (2)) and financial resources (equation (3)):

$$U=(Z, T_l, W(G), S(C(T_c, M)), \theta) \tag{1}$$

$$T=T_w+T_c+T_l-T_s \tag{2}$$

$$I \geq N+wT_w-pM-Z \tag{3}$$

Households gain utility from consuming a composite good Z, leisure time T_l, and water supply W. Water supply is a function of government policies G, such as infrastructure provision. Disutility comes from poor health and sickness S, which households can reduce by investing time coping T_c (e.g., by walking further to collect water from a protected source or by spending time treating water), and financial expenditures M on water treatment devices, higher prices at protected sources, or other capital costs. The parameter θ stands in a broad-brush way for heterogeneity in the tastes and preferences of households. Some may value leisure time more highly, for example, or place a higher priority on improving health (lowering S). Households allocate their total time T among leisure, time coping, and time spent earning wages T_w; they lose time T_s to illness (we assume a "unitary" household decisionmaking structure). Finally households are constrained by their budgets. Households must limit their total expenditures to the sum of income N not earned using time or labor (i.e., remittances, financial returns on investments) and their earnings from wage labor at a rate of w per unit time. Households spend money on the composite good Z (with a price normalized to one) and financial coping actions M which have a unit price of p.

Households maximize utility by deciding how much time to devote to wage labor T_w and water collection T_c, how much of the composite good Z to consume, and how many investments or expenditures to make in coping with poor water supply (M, at exogenous price p). Notice that $W(G)$ is exogenous to households; they cannot choose their current water supply regime in this model. Only government policies affect the baseline water supply situation in our model. As W(G) changes, so too would the optimal decisions households choose to make about time, consumption and financial coping mechanisms. An important policy question, then, is: how valuable to households is a change in water supply regimes, say from the current status quo $W^0(G_0)$ to an improved situation $W^1(G_1)$ where the government or a regulated operator invests money to extend (or repair) a networked, piped system? In other words, what is the total household willingness-to-pay (WTP) for this improvement? Using duality theory, we can define a "quasi-expenditure function" Ω that gives households the exact same utility U^0 that they had under the status quo water condition, and again optimize (take the first derivative) of this function (see *Pattanayak et al*. [2005] for a longer derivation). The household's total economic benefits, $\delta\Omega/\delta W$, of changing water supply situation W is:

$$\frac{\delta\Omega}{\delta W}=\left[p\frac{\delta M}{\delta W}+\frac{\delta T_c}{\delta W}\right]+w\frac{\delta S}{\delta W}-\lambda\frac{\delta U}{\delta S}\frac{\delta S}{\delta W} \tag{4}$$

The term $\delta\Omega/\delta W$ is the amount of income *N* that one could take away from a household at water situation W^1 and leave it with exactly the same utility as they had at water situation W^0. The three terms of this willingness-to-pay function are 1) the coping costs in terms of financial expenditures and lost wage income from time spent coping; 2) the costs of illness; and 3) any monetary value associated with pain and suffering from poor health *S* that is not associated with lost labor hours. One prominent component of this term would be the value households place on reducing mortality risk. Our analysis of coping costs will incorporate (theoretically) the first two terms but cannot capture the third, and is thus a lower bound on the total economic benefits of improving water supply. There are a number of other factors that may drive a further "wedge" between coping costs and total WTP, such as intrahousehold time allocation, suboptimal coping choices, possible income effects from improved water, and other factors (we again refer the reader to *Pattanayak et al*. [2005] for more discussion).

It is also possible that *W*(*G*) is not, in fact, exogenous to the household: some households may move to the area that best matches their preferences for job or income opportunities, water supply options, or other local public goods (in the spirit of *Tiebout* [1956]). Note also that $\delta/\delta M$ is the marginal utility of money, and if one makes the common assumption that the marginal utility of income is declining, one prediction from the model would be that coping costs increase with income, all else equal.

Although the term "coping costs"' is sometimes used synonymously with the terms "averting" or "defensive" expenditures in the environmental economics literature, our "coping costs" are not simply averting expenditures. Rather, they combine both expenditures made defensively *ex ante* – boiling water to make it safe to drink – with those made *ex post*, for example on treatment of diarrhea. The latter category are often called "cost-of-illness" studies in the health literature. Note also that we do not distinguish between expenditures on "improved" versus "unimproved" sources, but rather report all costs incurred in water collection and treatment. For example, a study examining the coping costs of poor quality piped water supply in an urban area might include the costs of treating piped water or buying bottled water, but exclude the monthly bills paid to the water utility since these costs would still be incurred if piped water was safe to drink. Piped supply in our setting is irregular and virtually no one reported paying volumetrically (as we discuss below), so this counterfactual is less clear.

A number of studies have examined the strategies that households use to cope with poor water supply, though many have studied the treatment behavior of tap water consumers in industrialized countries where water collection time is very small [*Larson and Gnedenko*, 1999; *McConnell and Rosado*, 2000; *Abrahams et al*., 2000; *Um et al*., 2002]. Furthermore, most existing studies in low-income countries have focused on urban customers, where intermittent supply tends to draw researchers' focus again to water treatment choices as well as water storage investments [*Whittington et al*., 1990; *Zérah*, 2000; *Pattanayak et al*., 2005; *Jalan and Somanathan*, 2008; *Vásquez et al*., 2009; *Katuwal and Bohara*, 2011; *Vásquez*, 2012; *Nganyanyuka et al*., 2014]. Of these studies, we could find only two that included empirical estimates of the time spent traveling and waiting for water [*Whittington et al*., 1990; *Pattanayak et al*., 2005]. Estimates of the total coping costs as a percent of income were not reported in all studies; they were 0.78% in Leon, Nicaragua [*Vásquez*, 2012], 1% of current income in Kathmandu, Nepal [*Pattanayak et al*., 2005], and 7.5% of income (primarily on bottled water) in Parral, Mexico [*Vásquez et al*., 2009]. The evidence for coping strategies in rural areas––where most of the remaining water supply coverage gap lies––is quite thin. We know of only three studies examining coping strategies in rural areas [*Pattanayak et al*., 2010; *Kremer et al*., 2011;

Jessoe, 2013], though there have been a number of studies using stated preference methods to measure willingness-to-pay for improved water supply directly. The focus of *Jessoe* [2013] is solely on water treatment choices in rural India, testing whether switching to protected, "improved" sources leads households to discontinue treating water, reducing expenditures but offsetting some of the quality benefits of protection. *Kremer et al*. [2011] use both revealed and stated preference methods to estimate the value of source protection in rural Kenya; although coping strategies, especially water treatment and water collection times, are a central component of the study, coping cost estimates are mentioned only briefly. The best available rural estimates are from *Pattanayak et al*. [2010], who evaluated a community demand-driven water supply program in four districts of Maharashtra, India. The authors measured time costs of both water collection and poor sanitation, costs of illness, storage costs and treatment costs in panel data from nearly 10,000 households. Time costs comprised over half of total coping costs [*Pattanayak et al*., 2010, p. 538).

3. Study Site and Demographics

We interviewed a total of 387 households near the small market town of Kianjai in September 2013, the dry season. Interviews were done in person with trained enumerators. Kianjai is approximately 20 miles from the city of Meru, in north-central Kenya. The study site was chosen purposefully because of the large number of existing water source options available (the work was part of a larger study on rural water source choices). The site was *not* chosen because we believed *a priori* that it had a water collection burden that was higher or lower than an average rural town in Kenya. Sample households were chosen randomly based on a transect approach. We provide more details on the sampling approach in the supporting information. A team of seven trained enumerators asked households a number of detailed questions in Meru (the local language) about the water sources that households use during both the dry season and the rainy season, including water uses, prices paid, treatment of drinking water, and others. We interviewed the household member "who is mostly responsible for water-related decisions such as where to get water and how much to collect." In three quarters of the households, this person was also the one "who collected the most water in the past seven days."

A typical sample household is Catholic and has five members. The household is led by a married couple, both of whom are around forty years old and have each completed seven years of education. Eighty-one percent of households have a child under age 15; the average household has 1.8 children. Twenty-four percent of households have a child aged two or younger, and half have a child aged five or younger. They own their house and two acres of land. The household has a private pit latrine, but does not have electricity. Kerosene is used for lighting and firewood is used for cooking and heating. There are two rooms in the main house and three other buildings in the compound. Monthly household income from all sources is approximately 18,600 Ksh or 216 USD. The largest source of income, on average, is from farm revenue. Thirty-nine percent of households, however, had at least one household member who earned income from full-time employment, part-time or seasonal employment, or business and self-employment. About 10% of households had more than one member earning income from these sources. Average food expenditure is 430 Ksh (5 USD) per household member per week or a total of 14,924 Ksh (174 USD) per month. Household assets include a cell phone (93% of sample households), bicycle (76%), and radio (82%). Thirteen percent own a motorbike. The typical household has four chickens, two goats, and two cows. Using data on durable assets, electricity connections, sanitation, building characteristics, and cooking fuel, we construct a wealth index using principal component analysis (PCA) following *Filmer and Prichett* [2001] and *Filmer and Scott* [2012], and assign households to wealth quintiles. Although water supply variables are often included in wealth indices, we exclude them to avoid potential confounding with other explanatory variables. (The supporting information document provides more details on the construction of the wealth index and describes average income by source.)

4. Water Collection Behavior

In this section, we describe the patterns of household water collection activities common in the study site. Households in our sample reported that they *could* use an average of 3.6 sources (median 4; max 6); 91% of the sample falls in the range of 3–5 sources. They reported they had actually used an average of 1.9 sources within the past 12 months and 1.4 sources in the past week. Sixty-eight percent of households reported

Table 1. Water Collected From All Sources, Organized by the Household's "Primary Source"[a]

	Dry Season			Rainy Season	
	Median Liters per Capita per Day	Median Monthly Collection (m^3)	Average % of all Water Collected From Primary Source	Median Monthly Collection (m^3)	Average % of all Water Collected From Rainwater
Private piped (60)	40	4.8	91%	4.8	63%
Private well (78)	42	7.3	96%	6.0	56%
Vended (15)	28	3.7	80%	3.4	76%
Public well (122)	25	4.2	75%	5.0	69%
Public borehole (72)	27	4.1	72%	5.1	75%
Public piped connection (32)	20	3.9	85%	4.2	69%
Surface, other public (6)	27	3.7	58%	4.7	73%

[a]Numbers in parentheses in the first column refer to the number of households (of a total of 387) who reported that this type of source was their "primary" source for "most purposes." For example, 60 households said a piped connection was their primary source.

using only one source in the past week. Because households may collect water from different sources to serve different purposes, we asked which water source the household primarily uses for different purposes, including drinking, washing around the house, cooking, bathing/personal hygiene, watering animals, and other productive activities. We also asked which source was their "primary" source for "most purposes." All but 11 respondents (2.8%) reported that their "primary" water source for these various purposes was the same, indicating that most households rely primarily on one source and use others as occasional or back-up sources. In other words, most households do not dedicate water from different sources (perhaps with different qualities) to different water uses. Furthermore, approximately three-quarters or more of the total water collected in during the previous 7 days was collected from the "primary" source (Table 1). For example, among the 60 households whose primary source is their own piped connection, the average household collected 4.8 m^3 per month from all sources during the dry season, and 91% of that total was from their piped connection. We therefore organize our *discussion* of households by their reported primary source for most purposes, although our coping cost estimates will include water collection from any source.

Figure 1 shows water sources and households in the study site, the latter grouped by type of primary source. The figure illustrates several features of the study site. First, a piped distribution network operated by a formerly-public, now-private water company (Imetha Water and Sanitation Company, IWASCO) serves the area. The system used to supply piped service to many households until the distribution network fell into disrepair in the 1990s and the raw water supply from the mountains east of the map became over-allocated. Many of the households in our sample *without* water supply at home were once served by this system and showed us their yard taps that were no longer working. IWASCO is now in the process of rehabilitating the network and expanding the raw water intake, but at the time of our fieldwork the households that had working IWASCO connections were clustered along the one distribution line which first ran along the main road and then branched off, running northwest from the main road.

Another group of households have piped connections to what is locally called "project" water. These are self-organized, self-financed distribution networks that typically divert untreated river water. Some households contribute labor and some cash for the construction and operation of these schemes. Once the pipes reach near to one's homestead, the household is expected to buy the connecting pipes in order to access the water. There is no volumetric charge for using the system, but households make periodic monetary contributions when the system breaks down and repair or maintenance is required. These small systems typically have little system storage, so the system is only as reliable as the surface water supply.

Approximately 40% of our respondents reported that a well (either their own or a neighbor's) was their primary source, and these are clustered where groundwater is relatively accessible, predominantly southeast of the main road (red dots show households whose primary source is their own private well). The northwest and northeast sections of the study area have less accessible groundwater, and households there are more likely to walk to water. Blue "water points" are public water sources mentioned by respondents, including handpumps and public connections to the piped system.

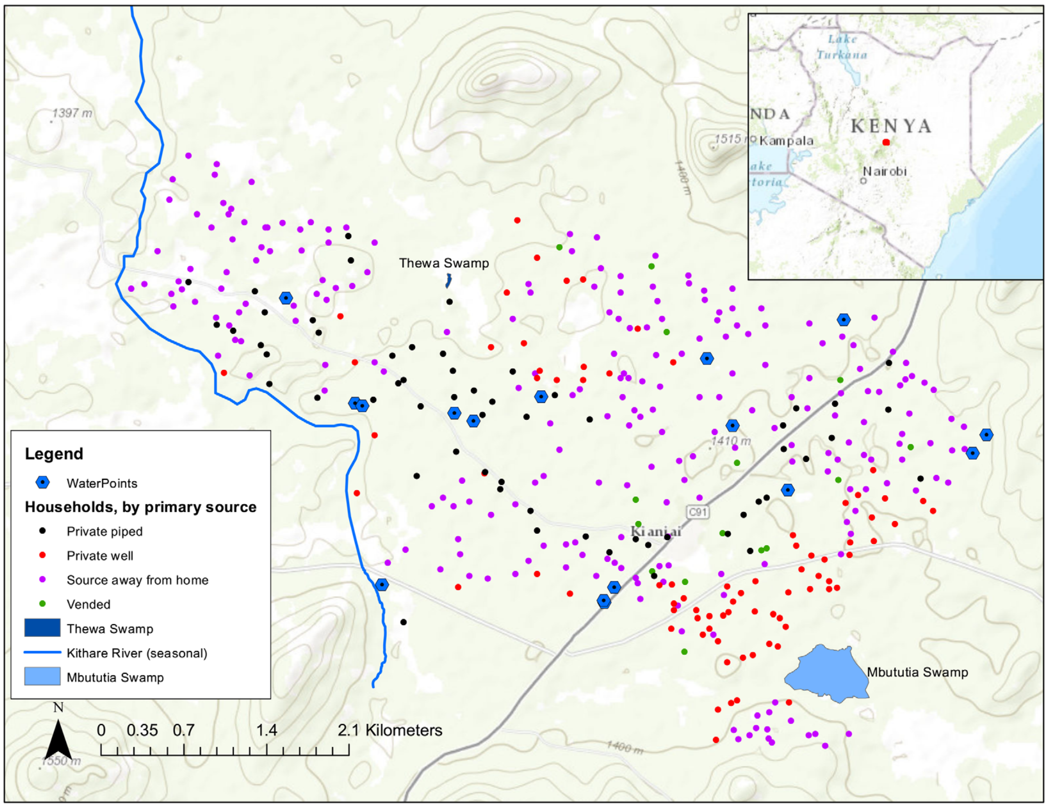

Figure 1. Households and water sources in study site, grouped by "primary" source.

Thirty-six percent of households in our sample say their primary source is at home, either private piped connections or private wells (first two rows of Table 1). Another 37% report that using a "neighbor's" source is their primary source; we categorize these as "public" sources in the table. The remaining quarter of the sample rely primarily on water from vendors (n=15, 4%), or walk to public water points that we attempted to geolocate. Table 1 reports the total volumes (from all sources; not just the primary source) collected both in terms of monthly cubic meters and liters per capita per day. Because of concerns for both recall problems as well as day-to-day fluctuations in water collection behavior, we asked how much water was collected in the past 7 days as well as a "typical" week in the dry season and rainy season. The dry season calculations in Table 1 are based on collection data for the "past 7 days."

As one point of reference, the *World Health Organization and WEDC* [2011] issued a technical note on water requirements in emergency situations such as camps for displaced populations. The report recommended a minimum of 7.5–15 L per capita per day (LCD) for basic survival, hygiene and cooking needs. Water requirements that include personal washing, washing clothes, and cleaning the home are roughly 50 LCD. As a second point of reference, *Howard and Bartram* [2003] categorize households with average consumption of 20 LCD as having "basic" access, those with average consumption of 50 LCD as having "intermediate" access, and those consuming 100 LCD or more as having "optimal" access.

Households with piped water are abstracting approximately 40 LCD, mainly because the system does not provide anything near 24 h, 7 day service. The median household with a piped connection receives water for 12 h per day, 3 days per week. Households with private wells are abstracting about the same amount per capita. Households with private wells abstract slightly more in total than those with private connections (third column) because of larger household sizes: the median household with a piped connection has four members versus six members for households with a private well. Households who travel for water are collecting less water, approximately 25–35 LCD.

On average, households reported using approximately 72% of the water collected for washing around the home, bathing and cooking, and (plausibly) 2% (or 14 L per household per week) for drinking. Eighty-five

Table 2. Perceptions of Water Source Characteristics Among Those Who *Could* Use That Source, and Water Treatment Behavior, Proportion of Respondents[a]

	Some Risk From Drinking Water	*Serious Risk* From Drinking Water	Water Tastes Poor	Using Source Likely or Very Likely to Lead to Conflict	Treat Water (If Used Source in Past Year)
Private piped	0.71	0.059	0.059		
Vended	0.49	0.33	0.36		
Public well	0.54	0.28	0.38	0.69	0.39
Public borehole	0.31	0.075	0.21	0.51	0.28
Public piped connection	0.52	0.096	0.13	0.56	0.20
Surface, other public	0.21	0.42	0.46	0.62	0.17

[a]Results for questions about health risk from drinking, poor taste, or the likelihood of conflict are based on responses from all households who said they *could* use the source, not only respondents who listed the source as their primary source. Respondents were asked questions about whether they treated water from a source if they had used the source in the past 12 months, even if it was not their primary source. Blank cells indicate that the question was not asked for that particular water source, i.e., respondents were not asked if collecting rainwater would lead to conflict with others.

percent reported collecting water for animals. The median collected for animals is 40L per household per day, so this is likely for smaller livestock like chickens and goats and perhaps a supplemental supply for larger livestock.

Nearly all (96%) of respondents said they could and do use rainwater during the rainy season, and total volumes collected from all sources increase during the rainy season among households without water at home (Table 1). One-third of these households stored water in small buckets, but the remaining two-thirds had invested in larger storage containers (greater than 50L). The median household storage capacity was 200L. Only two households reported having sufficient storage capacity to use rainwater as their "primary" source. These two households had storage capacities of 9 m^3 and 18 m^3. Nevertheless, most households report that a majority of their water comes from rainwater during the rainy season (last column, Table 1).

We asked households to rate the sources they *could* use in terms of taste of water from the source ("poor," "normal," "sweet," or "varies") and whether using the source is likely to lead to a conflict with neighbors ("not likely at all," "somewhat likely," "very likely"). We also asked about the perceived health risk of drinking from the source ("no risk," "some risk," or "serious risk"), though we did not ask respondents to distinguish between risks to healthy adults and risks to vulnerable groups such as infants or the elderly. For any source that the household had actually used in the past twelve months - even if it was not their primary source - we asked whether respondents treated water before drinking. These results are shown in Table 2. Respondents judged the quality of water from piped systems to be poor. This is not surprising because the supply from these systems is intermittent. Seventy-one percent of respondents with working piped connections thought that drinking water posed some health risk, roughly similar to other households' perceptions of their *neighbor's* piped connection or a public tap on a piped system (Table 2). These respondents were, however, more satisfied with the taste of the water than respondents using sources outside the home. Respondents also reported that water sources are a widespread cause of social conflict in the area (Table 2, fourth column). Seventy percent of respondents who said they could use a public well or tap thought using it would be "somewhat" or "very" likely to lead to conflict. Among well-owners themselves, 85% reported allowing their neighbors to use the well and 28% of those said that sharing had led to conflict with neighbors (24% overall).

Some households with private wells may have solved their collection time and "quantity" problem, although the median consumption of 42 L per capita per day is still fairly limited, and some households may not be able to collect as much water as they would like from their wells because of groundwater recharge rates or seasonally-varying aquifer levels. We did not specifically ask households if they considered the quantity of water collected sufficient for their needs. They have not solved their "quality" problems, at least in terms of their perceptions of the health risk of drinking water (we did not collect objective water quality data). They are largely aware of this. Figure 2 shows three fairly typical private wells in the study site. They are hand-dug, i.e., not machine-drilled, and are fairly shallow; the median well depth as estimated by our respondents is 30 feet. The well at left is considered "protected" since it has a raised concrete cap and steel lid to prevent surface contamination, though the rope and bucket could quickly recontaminate the well. The wells in the middle and at right are both uncapped and prone to surface contamination; they are also both safety hazards for small children. Among the households with private wells, 69% thought that

Figure 2. Private, hand-dug shallow wells in the study site.

drinking water from the well would pose "some risk" or a "serious risk" (Table 2). Among those using a neighbor's well or a public well, 82% and 87% similarly thought this drinking water source was a risk. In all of these groups, roughly a third thought the risk was "serious." Accordingly, 54% of those with private wells reported treating their water (discussed more below in section 5), and 33% thought the water tasted poor. Thirty-six percent of those using a neighbor's shallow well and 44% of those using a public well reported treating water.

Who is hauling water home? Households who collect outside the home have an average of 2.1 people who have collected water in the past 7 days. The person who collected the most water in the past 7 days was a woman in 76% of households, with an average age of 34 years old. Twenty percent of all water collectors were under age twenty. Only 11% of "primary" water collectors had paid employment outside the home.

5. Coping Cost Components

In this section, we present the methodology and results for each individual component of coping costs: the time costs of collecting water outside the home, financial costs paid for vended water or at paid sources, amortized capital costs for storage and rainwater collection, diarrhea treatment costs, and money spent treating drinking water. Section 6 then reports total coping costs (the sum of these five categories), explores the pattern of coping costs by decile of self-reported income and asset/wealth quintile, and explores correlations between household characteristics and coping costs.

5.1. Collection Time

We use responses from several questions to calculate the time spent collecting water from outside the home. First, we asked respondents how long it would take to walk to a water source, one-way, with a full 20L "jerrican" (a rectangular, hard plastic water storage container). Given that walking with an empty container should be faster, these times are multiplied by 1.75 to get roundtrip walking times. We are unaware of estimates comparing walking speeds with and without the burden of a 20L (20 kg) jerrican (see the supporting information document, section 4, for more discussion of this assumption, our distance calculations, and a comparison of walking speeds in the literature). Households walking to get water reported an average roundtrip walking time of 43 min (median 35 min) for sources that they have used in the past year (Figure 3a). There is considerable variation, however: the standard deviation is 43 min and the histogram shown in Figure 3 omits 13 households who reported roundtrip walking times in excess of 2 h. Figure 3a clearly shows modal responses corresponding to one-way times of 5, 10, 15, 30 (i.e., roundtrip = 30 * 1.75 = 52.5 min) and 60 min.

Because enumerators recorded GIS locations of houses and water sources, a second approach uses predicted walk times for those observations where we have GIS data. These are calculated with straight-line

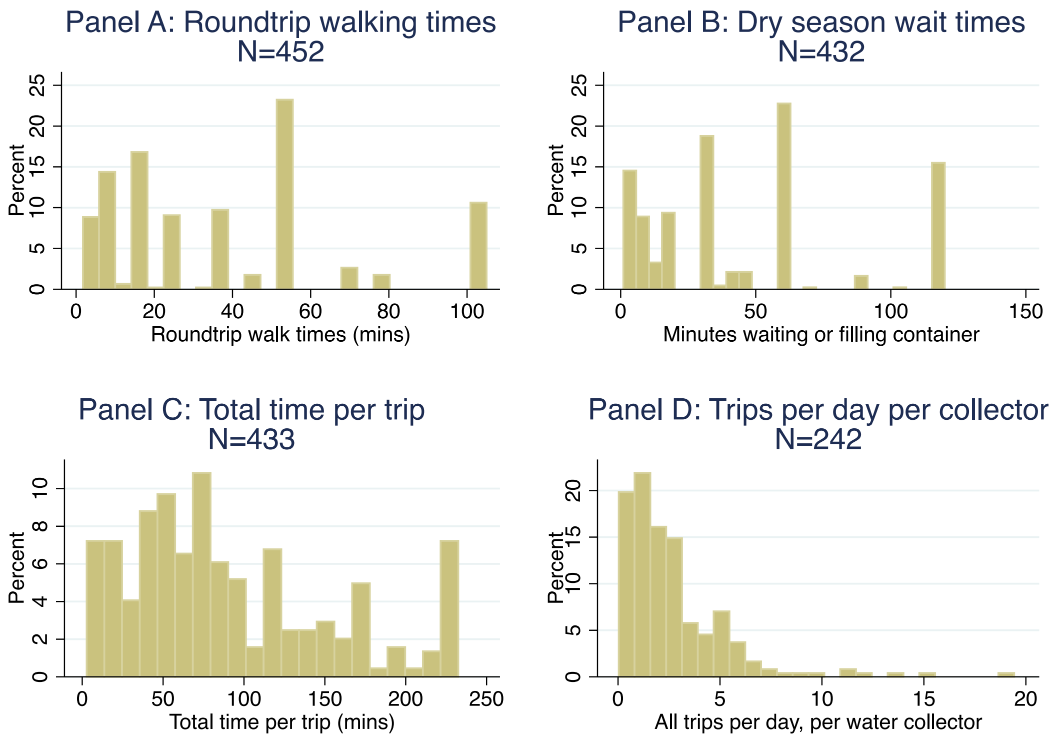

Figure 3. Reported walking and waiting times for sources away from home that were used by the household in the past 12 months. (a-c) 465 household-source combinations where the household reported using the source in the past 12 months. (a) Omitting 13 observations exceeding 2 h. (b) Omitting 33 observations exceeding 2 h per trip. (c) Excluding 32 observations exceeding 4 h per trip. (d) Based on data reported by households for the "past 7 days" (n= 242 hhs getting water outside the home at least once in past 7 days) and includes trips on foot as well as by bicycle or other means.

distances in GIS for 300 observations of household-water source pairs. Our results imply average walking speeds, encumbered with a 20L container, of 2.75 kph or 1.7 mph. These are somewhat lower than other reported walking speeds in rural Africa, though most published studies do not distinguish between walking with and without the weight of jerricans. Furthermore, because our straight-line distance calculations will underestimate the actual distance along roads, our "speed" estimates would therefore also be under-estimated (see supporting information for more details and discussion). We do not have geolocations for "neighbor's" sources, however, which were reported by a significant fraction of households. A third approach is to supplement the GIS-predicted times with median reported distances (in minutes) to a "neighbor's" source by sublocation (to account for spatial differences in the density of houses). Rather than mixing reported and predicted distances, for clarity we focus primarily on using unadjusted but truncated times, described in more detail below. We provide results using the other approaches as a sensitivity analysis. We also cannot rule out that households may be combining activities on these trips, such as socializing or visiting the market.

Thirty-three percent of households (n=127) reported collecting water by modes other than walking in the past seven days. The majority of these used bicycles, typically to carry one or two jerricans, though 13 households used carts or wheelbarrows to haul larger quantities of water. One household used a motorbike, and one reported using a car to collect water. We did not ask about how many minutes it would take to travel to a source using these different modes. Roundtrip time for bicycles are assumed to be half the reported walking time, and the time for cars and motorbikes to be one-quarter the walking time.

We asked households how long they spent waiting in a queue or filling their container during an average week in the dry season and in the rainy season. These average 55 min (median 30 min) in the dry season (Figure 3b). Figure 3b again shows modal responses at 30 min, 1 h and 2 h, and omits 13 observations where respondents said a typical wait exceeded 2 h. Although these reported times may be subject to recall bias and in some cases exaggerated, we cannot independently verify them without direct observation of sources. In a sensitivity check, we use median reported wait times (by source) to deal with the large outliers.

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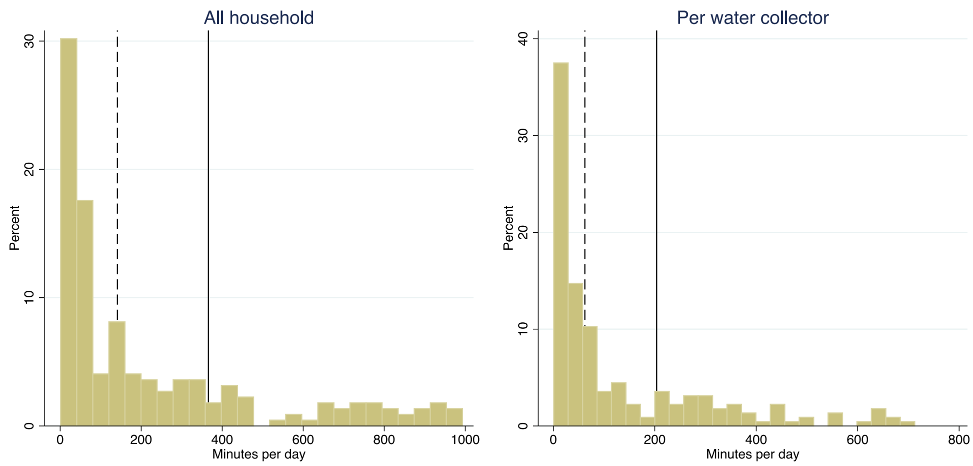

Figure 4. Total collection time (minutes) per day, per household and per water collector. *Notes*: n=245 households that collected water outside the home and reported a trip within the past 7 days. Histogram on left does not display 23 values over 1000 min/d per household; histogram on right truncates 17 values that exceed daylight hours (12 h * 60 = 720 min). The two black vertical lines show the mean (solid) and median (dashed) collection times.

We also do not observe whether households are able to leave the line––putting their jerrican in line as a placeholder––and do other things with their time. Reported wait times plummet to an average of 7 min (median 5 min) during the rainy season. Figure 3c shows the distribution of total times per trip for all households collecting water from a source outside the home, combining the walking and waiting data.

Households also reported the number of trips they took to collect water in the past seven days, during an average dry season week and during an average rainy season week. We focus on trips made in the past 7 days, which are least likely to suffer from recall problems. Households who made trips on foot reported making an average of 4.8 trips per day (median 4.3) in the previous 7 days; households who made trips by other means made 2.2 trips per day (median 1.9). Twenty-nine households reported making more than 10 trips per day. Because some households may have more labor available to haul water, we calculate the total trips per day per water collector (Figure 3d). Even after adjusting for water collectors, however, Figure 3d still shows a fraction of very high reported numbers of trips per day. Among the 25 households taking more than 5 trips per collector per day, one-quarter are collecting nearby, with roundtrip walking times to their primary source of 10 min or less. Four of the 25 households, however, report taking more than five trips per day to a source that takes over an hour to walk to and return.

We next multiply the total number of trips by the travel and wait times per trip reported above to produce the implied total collection time (Figure 4); these are the key estimates that we multiply by the value of travel time below to get economic costs of time spent hauling water. The figure shows the distribution of daily collection time per household on the left and per water collector on the right. Households spend an average of 6.1 h/d collecting water, and each water collector spends an average of 3.4 h/d (these are shown as the solid black vertical lines in the two plots of Figure 4). Both figures show distinct right tails with some households reporting very large total collection times, and the figures do not display 17 households with collection times per collector that imply more than 12 h per water collector (more than all daylight hours at our equatorial site). These households drive large differences in the mean and median times: median collection times are 2.4 h per household per day and one hour per water collector (dashed black vertical lines in the two plots). Fifty-six percent of households have daily collection times of 3 h or less, and 36% of households have total collection times per water collector of 30 min or less.

Rather than truncate values for travel times, wait times, or the number of trips that seem implausible, we truncate a household's total water collection time at what we feel is a reasonable upper bound. One upper-bound would be to assume that households cannot spend more than all 12 daylight hours for each water collector in their household; we would truncate any households with two water collectors at 2*12*60=1440 min. Instead, we assume, more conservatively, that water collectors spend no more than 6 h/d collecting water, which truncates total collection times for 44 out of 245 households that collected water outside the home.

Table 3. Economic Costs of Time Spent Collecting Water Collection Time: Sensitivity Analysis

	Dry Season				Rainy Season
	Reported	Reported, Truncated[a]	GIS Distances[b]	GIS + Medians[c]	Reported
Total Household Collection times (Minutes), per Day					
Mean	366	259	367	279	113
Median	141	140	147	172	12
95th percentile	1401	950	1401	980	440
Monthly Economic Time Costs (Ksh)––Individual Value of Travel Times From Stated Preference					
Mean	3,992	2,954	4,043	3,164	1,131
Median	811	654	807	986	29
95th percentile	18,977	13,508	21,116	14,006	4,140
Median % income[d]	6.4%	5.0%	6.7%	6.6%	3.2%
Monthly Economic Time Costs (Ksh)––Value of Travel Time = 50% of Wages					
Mean	3,201	2,262	3,211	2,422	753
Median	1,236	1,225	1,289	1,508	101
95th percentile	12,262	8,312	12,262	8,571	3,150
Median % income[d]	9.1%	9.0%	9.6%	12%	5.8%

[a]N=245. Households who reported no water collection times – those with piped water or private wells – are excluded from these calculations. Assumes households cannot collect more than 6 hours per day per water collector.

[b]Uses predicted walking times using GIS data and a linear fit between reported times and actual straight-line distances (see supporting information, section "GIS"). Uses reported times for "neighbor's" sources where no geospatial data are available, and no changes are made to waiting times or number of trips.

[c]Uses GIS-predicted distances where possible and median distances to "neighbor's" sources, calculated for each sublocation. Uses median wait times, calculated by source.

[d]Monthly economic costs divided by reported total monthly income (missing in three observations).

To place an economic value on this time, we use individual-level estimates of the value of travel time (VTT) based on results from a simple stated preference experiment where respondents were asked to rank new hypothetical water sources that varied only in distance from home and price per jerrican [see *Cook et al*., 2015]. The results used here are from a latent-class multinomial logit model. Information criterion test statistics indicated that a model with four classes best fit the data, and we use the individual-level predicted class probabilities to assign respondents to one of these four classes. The first class (34% of respondents) valued time at 50 Ksh/hr. A second class (18%) was relatively unresponsive to the distance to source and has an implied VTT that is very low (0.7 Ksh/hr). The third class (16%) valued time at 7.9 Ksh/hr and the fourth class (33%) at 8.3 Ksh/hr. The latent class model used no data on the household's socioeconomic characteristics, so use of these value-of-time estimates should not bias the regression models explaining total coping costs below. Respondents whose primary source was a rainwater collection system or a private, piped connection did not complete the exercise. Since we did not estimate VTTs for these households, we assume the value of travel time is 50% of unskilled wages, or Ksh 17.5, which we discuss more below. This assumption is unimportant, however, since collection times for these households are small.

Table 3 summarizes the results for the monthly economic cost of water collection under several scenarios; see table notes for descriptions of the four alternate methods of calculating travel times. Only households who reported nonzero collection times are included in the table, and the estimates are based on responses for the 7 days prior to being interviewed, which occurred in the dry season. Median total daily collection times are approximately two and a half hours per household per day. The average times range from 6 h (as reported) to 4.3 h (truncated). Using GIS-predicted walk times but not adjusting trips, wait times, or distances to "neighbor's" sources does not change the means much, though using median distances and wait times does. Total reported water collection times fall roughly 70% during the rainy season to a mean of 113 min/d; the median is 12 min/d. Supporting information Table S2 compares these estimates with total walking times per day if total travel time per trip is twice the reported one-way walk time with a full container, rather than 1.75x as used here.

Using our latent class value of travel time estimates, the median economic value of this collection time ranges from 654 Ksh to 986 Ksh per month depending on how collection times are treated, or 5.0 - 6.7% of reported monthly *cash* income. This income measure does not include the value of crops grown by households for their own consumption. The economic costs of collection are much lower in the rainy season: the median falls to just 30 Ksh, and the average falls to 1130 Ksh.

For comparison, we also present estimates using a commonly-used benchmark of 50% of the unskilled wage rates [*Pattanayak et al*., 2005, 2010; *Kremer et al*., 2011]. The field team estimated the unskilled wage rate to be 35 Ksh per hour in our site, implying a "benchmark" value of travel time of 17.5 Ksh/hr. This assumption results in lower average costs and higher medians. There are two factors affecting the comparison of results using the two different VTT estimates. The first is that they obviously imply different VTTs: using the latent class values, the (class-weighted) average VTT is 21 Ksh/hr, or 60% of unskilled wages versus 50% in the benchmark. Other things equal, this should increase total economic costs of water collection. The second factor is the amount of time spent collecting water among the respondents in each class. If they were distributed similarly across the three classes, again we would expect that using the latent class VTTs would increase total economic costs. They are not distributed similarly, however. The average (truncated) daily water collection time among the143 households predicted to be in class 1, with a VTT of 50 Ksh per hour, is 170 min. The average time among the 136 households in class 3 or 4, with lower VTTs of approximately 8 Ksh per hour, is 19 min longer. Among the 46 households predicted to have a VTT of 0.7 Ksh per hour, average daily collection times are 271 min, or over an hour longer. The median times for these three groups are 26, 65 and 74 min (supporting information Figure S1 shows the cumulative distribution of collection times by class.) In other words, the latent class model of stated preferences predicted households with longer water collection times would have lower VTTs. The results in Table 3 combine these two effects. The mean economic costs are indeed higher using these individual VTTs, but the medians are lower.

5.2. Financial Water Costs

Prices charged at public water points or at "neighbor's" sources were generally Ksh 2 or Ksh 2.5 per 20L jerrican. Households report modest differences in prices at different sources. Although some of this dispersion could be recall or inaccuracy problems, it may reflect real differences in prices charged to different households. We therefore use reported prices rather than taking averages or medians. We found no cases of households paying for water away from the home periodically rather than volumetrically. In 15 cases, households said they could use a source away from the home and reported paying per period rather than volumetrically, but none of them actually reported collecting water from that source in the past 7 days nor in an average dry or rainy season week, so it is likely they were mistaken about a source they do not use. We multiply these volumetric prices by the number of jerricans the household reported collecting from that source in the past 7 days and multiply by 4.29 (30/7) to convert to monthly costs. Given the concern above with potentially unrealistic numbers of trips, volumes are truncated in a similar manner here to avoid inflating the average financial costs paid for water collected. We truncate households who said they collected more than 200 L per household member per day. This affects 10 records, three of which are households buying from water vendors, 6 collecting from their private well (zero financial costs) and 1 household using its piped system (again, zero volumetric costs). Given the total volumes collected (Table 1), the average monthly financial expenditure by the 232 households whose primary source is neither at home nor water vendors is Ksh 410 (USD 4.8). This figure excludes occasional expenditures by these households on distributing water vendors, which we discuss in more detail below.

We assume zero marginal financial cost for households with private wells. Only five of 87 households with wells used an electric pump; the remainder used a bucket and rope (n=79) or a handpump (n=3). The cost of the electricity needed to use a pump is low, and without information on the model or efficiency of the electric pumps, our estimate of the electricity costs would be inaccurate. We thus choose to omit pumping costs for these five households.

Similarly, few households with piped connections face positive marginal water prices. Seventy-six households reported that they have a working piped connection, including 16 for whom it is *not* their primary source. Of these 76 households, 18% reported paying nothing for their water and 51% paid a one-time amount to obtain their connection, most commonly Ksh 300 (USD 3.5). Twenty percent (n=15) pay a non-volumetric monthly fee, typically Ksh 500. Only five respondents said they have a working meter, receive a bill and pay a volumetric charge. Only one respondent reported this charge, however (Ksh 5 per cubic meter). Rather than calculate volumetric bills, we used the previous month's reported bill to estimate the household's monthly financial cost.

Eighty percent of respondents said it was possible to buy vended water where they live. Eighty respondents (21%) said they bought vended water during the past seven days, and 189 (49%) said they purchase vended water in an average dry season week. As shown in Table 1 above, however, only 15 households said that they relied primarily on vended water, so most households use it as a supplemental source. Most of the 189 households who buy vended water buy less than 2 jerricans per person per day. Although a small number of respondents reported volumetric prices of Ksh 15, Ksh 20, or Ksh 30 per jerrican, 81% reported that the price per jerrican in the dry season was Ksh 10. We use prices reported by the household, since a vendor may charge different households different prices depending on their distance from the vendor's water source. Average monthly expenditure on vended water in the entire sample is Ksh 254 (USD 2.95); the median is zero. Among those who purchased any vended water in the past 7 days, mean and median monthly expenditures are Ksh 1,227 (USD 14.3) and Ksh 879 (USD 10.2). These figures and the totals presented further in the paper censor four observations where the household reported buying more than 10 jerricans per day, but did not list vending as their primary source. These amounts, some of which imply monthly expenditures of USD 228, are unlikely, so we censor the number of jerricans at ten for these four households. The study team was told that water vending was nonexistent in the rainy season, so the questionnaire did not ask about rainy season water vending expenditures.

Sixty-seven respondents reported buying bottled water in the past seven days; 75% of these bought 3 L or fewer for the whole household over that time. A survey of local market prices for bottled water found a cost of 50 Ksh for 1 L, the most common type of volume purchased by households.

5.3. Capital Costs

The most common types of capital investments for coping with unreliable water supply are (a) purchase of storage containers and (b) construction of private wells. Investments in bicycles, carts and motorbikes, etc. might be seen as representing coping costs to ease the burden of water collection. These assets have multiple purposes, however, so lacking information on how important water collection was to the decision to purchase them, we omit them as coping costs. For all assets, we convert capital costs to monthly costs by amortizing using a 10% real discount rate.

We asked households with piped connections and households who said they use rainwater about investments in storage equipment. Eighty-nine percent of households with working piped connections had invested in storage. The majority purchased tanks of 100 and 200L capacity, though a quarter purchased tanks that stored 1 cubic meter or more; average total storage capacity is 1,153 L (median 340 L). We asked about the cost (in today's dollars) to purchase their largest tank, which averages Ksh 5995 (USD 70). Amortized over a useful life of 15 years at 10%, this is equivalent to a monthly cost of Ksh 59 (USD 0.69). Among the 176 (70%) households who said they had built a rainwater collection system, the average system has a total storage capacity of 2.4 cubic meters and would cost Ksh 9,000 if purchased today. These capital costs are equivalent to an average monthly payment of Ksh 87. These averages are affected by a few very large systems; median monthly capital costs are Ksh 7. Other households told us they had purchased smaller rainwater storage capacity. We assume a useful life of 7 years for what are most likely plastic storage containers, based on survey evidence from India [*Pattanayak et al.*, 2008], and assume that each liter of storage costs roughly 10Ksh based on a survey of local prices.

Households with private wells estimated that digging a similar well today would cost an average of Ksh 35,000 (USD 407), or Ksh 970 per foot of depth. Because eight respondents could not estimate the cost, and because of several outliers, we use predicted well digging costs from a simple linear model of reported depth on reported cost. Amortizing over 20 years at 10%, these imply average monthly capital costs for the 87 households with wells of Ksh 348 (USD 4.04).

5.4. Diarrhea Treatment Costs

We asked households how much money they had spent on diarrhea treatment costs in the past seven days, and multiplied these estimates by 4.29 to get monthly expenditures. At the level of an individual household, this is likely an overestimate of the diarrhea treatment costs given that diarrhea is acute and may not require a month of care and treatment. At the population level, however, the same logic implies that households who did not have a diarrhea case in the seven days prior to the survey may have had a case at some other time in the previous month. Nevertheless, diarrhea treatment costs are low. Twenty-nine respondents (7.5%) had spent money on diarrhea treatment and the average weekly expenditure among these

Table 4. Monthly Coping Costs (Ksh) During the *Dry Season*, Excluding Time Costs, by Primary Source, Mean (Top) and Median (Bottom)[a]

	Vending Costs	Bottled Water	Water Purchase	Capital Invest.	Diarrhea Treatment	Water Treatment
Private piped (60)	15	111	159	136	50	891
Private well (78)	38	185	16	380	48	817
Vended (15)	1167	271	47	80	50	214
Public well (122)	367	33	402	46	128	595
Public borehole (72)	368	185	454	39	32	613
Public piped connection (32)	48	33	395	20	0	461
Surface, other public (6)	657	36	130	77	0	462
Median	**Vending Costs**	**Bottled**	**Water Purchase**	**Capital Invest.**	**Diarrhea Treatment**	**Water Treatment**
Private piped (60)	0	0	0	60	0	278
Private well (78)	0	0	0	375	0	246
Vended (15)	1114	0	0	7	0	123
Public well (122)	0	0	279	17	0	123
Public borehole (72)	0	0	300	14	0	2
Public piped connection (32)	0	0	257	10	0	74
Surface, other public (6)	300	0	0	29	0	467

[a]N=325. 1 US$= 86 Ksh at the time of survey. Water treatment costs for vended and piped water are based on a predicted probability of treating water.

households was 408 Ksh (USD 4.74). Among all households, including those who reported no diarrhea treatment costs, the average weekly cost is 31 Ksh (USD 0.36). The causes of diarrhea are complex, however, and these costs should not be attributed entirely to poor water and sanitation. For lack of a better estimate, we attribute half of these costs to water and sanitation.

5.5. Water Treatment Costs

The survey asked whether and how water was treated before drinking, with closed-ended answer codes of "boiling," "filter," "stand and settle," "chlorine/Waterguard/Pur," "solar disinfection," and a category for other methods. We rely on a number of assumptions to calculate total treatment costs. First, we assume that only the volume of water reported used for drinking in the past 7 days was treated. For sources away from the household, we asked if they treat "always" or "sometimes," and assume that the latter implies half the volume of water is treated. This frequency question was not asked for water from rainwater or private wells; we assume that if a household reported treating water from these sources they "always" did. The treatment options "stand and settle" and "filter" are assumed to have no financial cost, since costly household point-of-use filtering devices are not common in the region. Furthermore, only 9 people reported filtering water.

For the 43% of households that reporting boiling water, we base the cost on the predominant fuel used for cooking, which is firewood for 80% of households. We assume that 1 kg of wood is needed to boil 1 L of water [*Sobsey*, 2002]. Based on a survey of local prices, the cost of firewood is 800 Ksh for 70 kg of firewood, or 11 Ksh per liter (for purposes of comparison, recall that the local price of bottled water is 50 Ksh per liter). Fourteen percent of households use biomass (e.g., maize cobs, leaves) as their main source of energy for cooking. We maintain the assumption that 1 kg of biomass is needed to boil 1 L, but assume the price is half that of firewood, since biomass is more often collected locally and because market prices of biomass were unavailable. Fifteen households (4%) reported using charcoal and 1% use electricity; we use the same treatment cost per liter as we use for firewood for lack of better information. For the 14% of households who reported chlorinating, we use a local price for Waterguard-brand chlorine of 25Ksh/1000 L, or 0.025 Ksh per treated liter. A number of households with private wells reported adding chlorine directly to the well. We do not have information on what, how often, or how much they add to the well, although given chlorine's price this omission is unlikely to introduce a serious downward bias in our treatment cost estimates. Mean monthly average treatment costs among the entire sample, including those who do not treat water, are Ksh 658 (USD 7.7, median = Ksh 168).

Through a survey implementation error, respondents were not asked about treatment of drinking water from vendors or from piped connections. We predict treatment costs based on a regression model of total

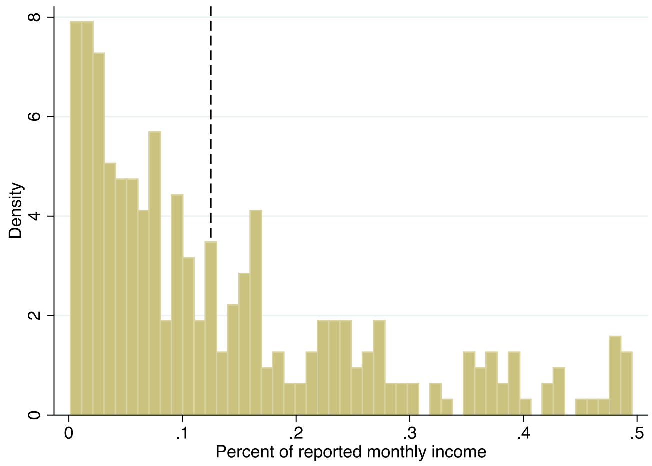

Figure 5. Coping costs as a proportion of reported household monthly income. Uses truncated collection times and individual-level value of travel time estimates. Figure does not display 58 observations with coping costs over 50% of reported cash income.

monthly treatment costs for all other households (supporting information Table S3). As expected, treatment costs increase with perceived risk, education, and assets. They are negatively but weakly associated with diarrhea treatment costs, and the explanatory power of the model is fairly low ($R^2=0.13$). Predicting out-of-sample based on these covariates produces the monthly treatment costs in Table 4 for households whose primary source is vended or piped water.

Among the 69% who reported treating their water at all, average and median costs are Ksh 957 and Ksh 491. This figure is driven overwhelmingly by the 43% of respondents who said they boil water. Drinking water in household containers was not tested for microbiological quality, nor did we verify that the large fraction who said they boil water actually do. Some respondents may have wanted to give the "correct" answer regarding water treatment (i.e., "social desirability" bias). Furthermore, it is possible that households who said they "boil" water are actually just heating it on a residual fire (and thus not using additional firewood) and not bringing water to a full roiling boil as required. (We thank a reviewer for pointing out this possibility.) It seems likely that, on the whole, these estimates are biased upward.

6. Total Coping Costs

Using our "truncated" approach to estimating travel times and valuing them with individual-level values of travel times, the median household in our sample incurs total economic costs of dealing with unreliable water supply in the dry season of 1777 Ksh (US$20.7) per month. The total average cost is 3380 Ksh (US$39) per month. Expressed as a percentage of reported monthly cash income, the median household incurs costs equal to 12.5% of its reported cash income. Ninety-five percent of respondents said coping costs were at least 1% of income, 73% said they were more than 5% of income, and 56% said they were more than 10% (Figure 5). Total monthly coping costs tend to be higher for respondents in lower quintiles of reported income, in contrast to the theoretical prediction outlined above, though the results are not monotonic

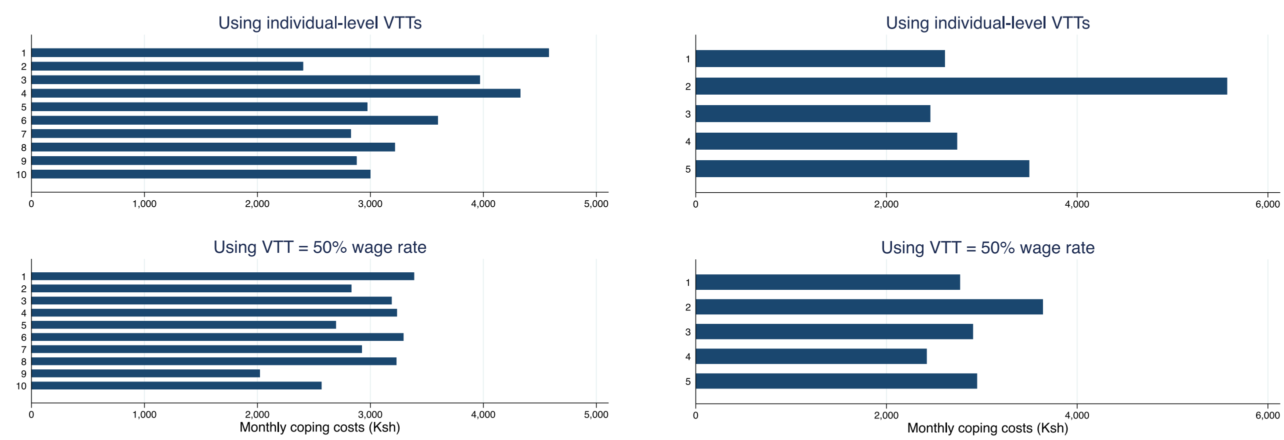

Figure 6. Average total monthly coping costs during the dry season, by (left) income decile and (right) wealth quintile. N=387. Uses truncated collection times, as described in the text. The first decile or quantile is the poorest group. 1 US$= 86 Ksh at the time of fieldwork.

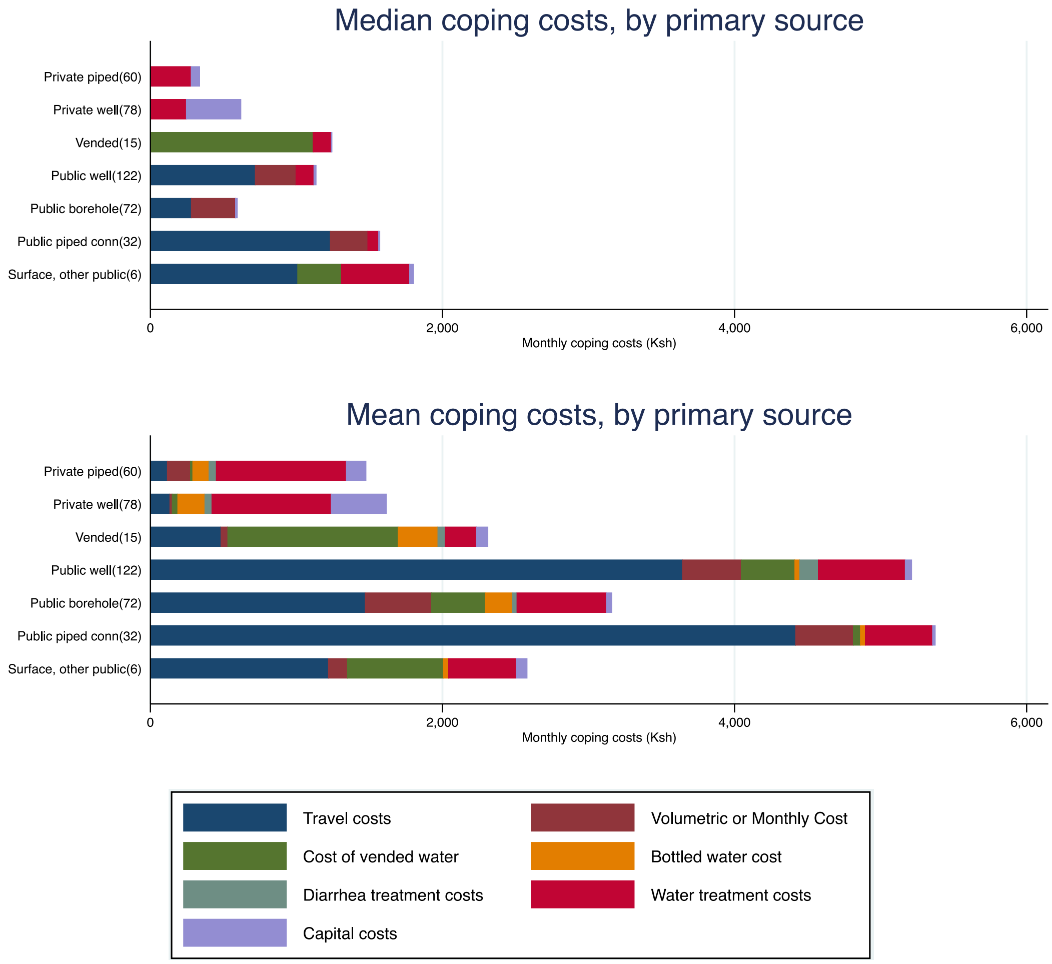

Figure 7. Mean and median total monthly coping costs (in Ksh), by primary source. N=387. Uses "truncated" travel time approach and individual-level value of travel time estimates. Two respondents with large rainwater collection systems not shown. 1 US$= 86 Ksh at the time of fieldwork.

(Figure 6, left). There is no clear pattern of results by wealth quintile (Figure 6, right). Total median coping costs fall to Ksh 855 (USD 9.9) during the rainy season; the mean coping costs in the rainy season are Ksh 2,137.

Figure 7 breaks down coping costs by category; for respondents who rely primarily on sources away from the home, the majority of costs are travel time costs. The figure again illustrates the impact on summary statistics of households who report large travel times - coping costs calculated by subgroup medians are much lower than means, though still a significant fraction of reported household income. One surprising result is that households who rely primarily on vended water have *lower* total coping costs (median = Ksh 1973) than households walking to collect water (median = Ksh 2265). If costs are really higher for households walking to get water, why would they not just hire vendors themselves? This is driven largely by differences in household size and thus total water collection. The fifteen "vended" households have an average household size of 4.1 members versus 5.7 members in households carrying water home, and total water collected

Table 5. OLS Regression of Total Monthly Coping Costs[a]

Primary source is piped connection	−2419.5***	(−3.24)
Primary source is private well	−2958.3***	(−4.40)
Primary source is vended water	−833.9	(−0.61)
Income decile	473.0**	(1.97)
Income decile * HH Size	−95.8**	(−2.33)
Resp. has primary education	−448.2	(−0.79)
Age of respondent	18.6	(0.92)
Household size	1212.1***	(4.72)
Constant	−2471.8	(−1.36)
Observations	381	
R-square	0.16	

[a]N=387. t-stats in parentheses; $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$.
[a]Use "truncated" travel time approach and individual-level value of travel time estimates.

in the past seven days is 710 L among vended households and 1136 L among households who walk to water. Households who rely on water vendors are indeed somewhat wealthier: their total monthly income is Ksh 15,747 compared to Ksh 14,980 for households carrying water. A further possibility is that, although households carrying water may incur large economic burdens, it is not easy for them to convert these economic costs into financial resources, i.e., convert saved time into money to pay vendors.

Finally, we regress total monthly coping costs on characteristics of the household (Table 5). Households with piped connections or private wells at home have lower monthly coping costs than those traveling to get water. After controlling for type of primary source, household size, and interacting household size with income decile, we find that households in higher income deciles, all else equal, do in fact incur higher coping costs. This is partly driven by the fact that households with sources at home have higher incomes than those walking to collect water (see supporting information Table S8). Larger households with larger needs for water collection (but also a potentially greater supply of water collectors) have higher monthly coping costs, although the marginal effect of adding an additional household member declines with household income.

7. Conclusions

Using a carefully-constructed picture of households' daily water behaviors in this area of rural Kenya, we find that the total economic costs of dealing with unreliable or distant water supply are 3400 Ksh per month, on average (US$38) (median = Ksh 1780, or US$21). The typical household incurs financial and economic costs equal to 12.5% of their reported cash income, and just over half incur costs greater than 10% of income. As a point of comparison, this total monthly coping cost is on par with the average water bill among US utilities surveyed in 2014 by Raftelis and the American Water Works Association [*AWWA*, 2015], which averaged approximately USD$33. It is also much higher than the water bill of a typical household in Nairobi that is connected to the piped system. According to the 2014 tariff schedule, a customer using 10m^3 (roughly double the consumption among households in our site) would pay $2.76 for water service plus a wastewater charge of $1.70. The tariff structure in Nairobi is much too low to cover operations and maintenance, let alone capital depreciation, and many households in Nairobi likely incur their own costs in coping with intermittent supply (storage, treatment, or bottled water purchases). But the comparison highlights an easily overlooked fact: the economic burdens of poor water supply often falls more heavily on unconnected rural customers (or those in unconnected urban settlements) than on households with piped connections.

Our results are driven primarily by time costs, but treatment costs and monetary expenditures to public taps, neighbors, and vendors were also important. About one-third of households in our study site had sources at home - either piped connections or private wells - where capital investments in storage capacity were also important. A small fraction of households incurred large costs relying on vended water. Forty-three percent of households reported boiling drinking water, implying nontrivial water treatment costs. We note again, however, that these treatment costs may be an overestimate, and that we used a model to predict, rather than observe, treatment costs for water purchased from vendors or abstracted from a household's own private connection. Omitting these predicted treatment costs, mean total coping costs for households who rely primarily on vendors falls from Ksh 2298 to Ksh 2084, and from Ksh 1433 to Ksh 542 for households whose primary source is their own private piped connection. Omitting *all* treatment costs lowers the median coping costs in the entire sample from Ksh 1780 to Ksh 968 (US$11.3) (see supporting information Figure S3).

But for most households, the majority of costs are driven by the daily burden of bringing water home. The median household reported spending nearly two and a half hours per day collecting water. Although we acknowledge the potential pitfalls of relying on households' own reports of the time they spend collecting, a range of approaches for handling collection times and the value of time imply that, for households without water at home, the median time costs are Ksh 700 - 800 per month, approximately 6.0% of income. In September 2015, the United Nations adopted the new set of "Sustainable Development Goals" to replace the Millenium Development Goals. One of the eight "targets" for Goal 6 on water and sanitation is to "achieve universal and equitable access to safe and affordable drinking water for all." A 2015 "Methodological Note" on proposed measurement toward the SDGs includes the standard that sources should be close enough such that a round-trip collection trip, including queuing, should take no more than 30 min [*WHO and UNICEF*, 2015]. Since most households in our site collect 20 L per trip, it is worth noting that the implicit economic cost for a household just barely meeting this 30 min standard would be Ksh 8.7 per jerrican (using our benchmark VTT estimates), or from 0 to Ksh 30 per jerrican (using our individual VTTs). The financial cost most pay, however, is Ksh 2.

Household coping costs such as estimated in this paper are likely to increase in the future due to the effects of climate change on precipitation and temperature. In some locations increasing hydroclimatic variability will change households' choice sets of water sources. Some wells and surface water sources may go dry during droughts. Increased flooding may destroy infrastructure and contaminate water sources. The quality of water sources and water stored in the home also may be affected by increasing temperatures. Households in rural areas may thus walk farther from home to collect drinking and cooking water and incur increased time and expense for point-of-use treatment. Increased hydroclimatic variability and the likely associated increase in coping costs remind us that solutions to local water problems–such as those in one area of rural Kenya discussed in this paper–are always contingent and subject to change. Our estimates of household coping costs will change in the future as household demand for improved services shifts, and as supply-side conditions and technologies change.

As mentioned in section 3, the water utility in the region (IWASCO) is in the process of rehabilitating the failed piped distribution system. Is this a good investment? Could households afford to connect to the new system? Lacking detailed cost data from IWASCO, we use a rough approximation of US$0.80 per cubic meter in [*Whittington et al*., 2010, Table 2.1, p. 485); these do not include any networked wastewater collection system. When households are (re)connected to the distribution system, we would expect total volumes of water used to increase, though this will be a function of the price that IWASCO ultimately charges and other taste and structural characteristics of the household. As a rough estimate, assume that households will use 110 L per capita per day, or 20 cubic meters per month for a household of six members. We would estimate the total economic costs of providing piped water service to be US$16, or roughly 1400 Ksh per month. We estimate that 57 percent of households in our survey have total monthly coping costs in the dry season that exceed US$16. At a lower bound unit cost of US$0.35 which excludes any opportunity cost of raw water, has minimal storage and simple chlorination treatment, and uses cheaper PVC pipe for the distribution network, we estimate that 78% of households have dry-season coping costs exceeding the monthly cost of US$7. These estimates use individual-level VTTs. Using a value of time benchmark approach (50% of the unskilled wage rate), the corresponding percentages are 61% and 79%.

Another way of examining the question would be through the lens of the "5% rule": households cannot afford to spend more than five percent of their monthly income on water and sanitation services. From this perspective, even if all of the economic coping costs could be converted to financial resources to pay for full-cost water tariffs, some in the sector would object to a piped system where many people were paying more than 5% of their income. What fraction of houses have coping costs over US$16 per month *and* could "afford" full-cost tariffs of US$16 per month? Only eight percent of households fit this criteria, and 42% fit a similar criteria for the low-cost option (coping costs greater than USD 7, and USD 7 is less than 5% of income).

This affordability criteria paints a more pessimistic picture for the financial sustainability of IWASCO's rehabilitation plan, but is in our view misguided. Our estimates suggest that many households are *already* spending the equivalent of more than 5% of monthly cash income on managing their water supply situation and coping with its effects, and would be likely to connect to a rehabilitated system even with full cost pricing. These coping cost figures may be underestimates because they will omit any benefits of reduced mortality risk. Furthermore, if the Kenyan economy continues to grow and the opportunity cost of water collectors' time increases, the economic costs of collection will increase. On the other hand, coping costs are lower during the approximately five months of the rainy season. Most importantly, though, this conclusion depends critically on a household's ability to convert economic losses of time into money to pay for water bills. This is a potentially important concern given that only 40% of households had a member who worked for wages, and is likely a concern in many rural areas of developing countries.

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