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RESEARCH ARTICLE

Benefits of piped water connections in underserved communities: A matched household comparison in Accra, Ghana

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Abstract

A quarter of the world's population lacks access to safely managed water. In Accra, Ghana, where less than half the population has a piped connection on premises, improving access is a government priority. This study used a quasi-experimental design to explore benefits of on-premise piped connections among direct (connected) and indirect (neighbors of connected households) users. Among 2,521 households surveyed, 720 (29%) had access to piped water on premises. Piped water was primarily available intermittently, with only 17% of connected households reporting that piped water was available every day. Most connected and unconnected households (90%) reported using packaged water for drinking. Households with a piped connection on premises experienced greater convenience and time savings: they were less likely to report cost barriers (Odds ratio (OR) 0.26; 95% confidence interval (CI): 0.14 to 0.48), less reliant on supplementary water sources (OR 0.45; 95% CI: 0.34 to 0.59), and collectors saved an hour fetching water per week (95% CI: 38–84 minutes). However, these households were less likely to have their domestic water source available every day (OR 0.13; 95% CI: 0.09 to 0.18) and equally likely to store water (OR 1.04; 95% CI: 0.69 to 1.56). Indirect users were less likely to be dissatisfied with their primary domestic water source (OR 0.45; 95% CI: 0.31 to 0.67), but otherwise benefits were less pronounced. We found no differences in perceived water security or income-generating activities associated with piped connections. These findings provide nuanced insights into the benefits of increasing piped water access in Accra's underserved communities. In this setting, the benefits of piped water services will not fully materialize until all households have access to a connection on premises and issues of intermittent supply are addressed.

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Introduction

There has been substantial progress towards ensuring access to safe drinking water for all (Sustainable Development Goal 6.1) since the turn of the millennium. Approximately 2.1 billion people gained access to safely managed drinking water [1], the highest level of water service, defined as an improved source that is 1) located on premises; 2) available when needed; and 3) free from fecal and priority chemical contamination [2]. However, an estimated 2.2 billion people still lack access to this level of service [1], and a recent study using geospatial data suggests it could be as high as 4.4 billion people [3].

This lack of access to safely managed water is associated with numerous adverse effects, impacting health, educational and economic development, gender equality, and mental and social wellbeing. Globally, an estimated 1.4 million deaths and 74 million disability-adjusted life-years could be prevented annually by providing universal access to safe water, sanitation, and hygiene (WASH) [4]. Several studies have documented the impacts of unsafe WASH on educational and economic opportunities, including through absenteeism from school or work [5], and impaired cognitive development [6]. The burden of coping with unsafe water access has long been known to disproportionately fall on women and girls [7]. The impacts on mental and social wellbeing have received more attention as an emerging area of research over the past two decades, finding that poor water quality and inadequate quantity, as well as inequalities in access to safe water, are key psychosocial stressors [8].

The majority of people without access to safely managed water reside in low- and middle-income countries [1]. In sub-Saharan Africa, 234 million people in urban areas still lacked access to safely managed drinking water in 2022 [9]. Cities struggle to provide adequate water infrastructure for current populations, and rapid urbanization is compounding these unmet demands [10]. This rapid urbanization is often characterized by the growth and expansion of communities that have limited access to basic infrastructure services [11,12], which we define here as underserved communities. Climate change is intensifying these challenges by further disrupting water availability in underserved communities [13].

In underserved urban communities, households frequently need to rely on multiple sources to fulfill their basic needs for drinking and domestic purposes [14]. This reliance on multiple sources is not only because of a lack of access to on-premise piped water, but also due to challenges associated with the quality of service, including piped water supplies that are only available intermittently [15]. Where on premise taps are available, access is often shared among multiple households [16], meaning that households with their own tap are direct beneficiaries, while other households can benefit as indirect users from having access to a neighbor's tap. However, available evidence documenting benefits of piped water focuses predominantly on rural settings [17–19], where occupation types, income levels, population density, availability of alternative sources, and community dynamics can be very different from large cities. In urban areas there is an unequal distribution of access to piped networks between communities. Expansion projects have attempted to reduce this inequality [20], and rigorous evaluations of these piped access expansions exist [21].

However, the benefits that new users derive from on-premise connections in underserved urban communities have received limited attention. Additionally, the existing literature mainly documents benefits to direct users, while benefits to indirect users remain poorly understood. Practitioners generally assume that indirect users experience similar benefits as direct users, but there is no evidence to substantiate this assumption to our knowledge.

In the Accra metropolitan area, Ghana, only 45 percent of households have a piped water connection on premises [22,23], and this proportion drops to less than 30 percent in informal settlements and peri-urban areas [24]. Instead, households rely on multiple alternative water sources, including packaged water, tanker trucks, boreholes, public taps, rainwater, and surface water [25]. Among national policy makers, there is consensus for the need to improve water service delivery in underserved communities [26]. Aligned with these policies, Ghana Water Limited (GWL), the national water utility mandated with providing piped water services to urban areas across the country, has been expanding on-premise piped water connections in Accra's underserved communities since 2017 under its Low-Income Customer Support Department. These expansion projects provide an opportunity to fill knowledge gaps on the benefits of household piped water access in these settings.

This study aimed to explore both direct benefits (for connected households, compared to unconnected households) and indirect benefits (for indirect users relying on their neighbor's connection compared to non-users). We hypothesized that access to piped water on premises would be associated with positive benefits, such as being more likely to use water for income-generating activities, and needing less time to fetch water, both directly for connected households and indirectly among unconnected households relying on their neighbor's connection.

Materials and methods

Ethics statement

The Ghana Council for Scientific and Industrial Research (CSIR) Institutional Review Board (IRB) reviewed and approved the protocol (# RPN010/CSIR-IRB/2023) in June 2023. Written informed consent was provided by survey participants and by community leaders, typically chiefs within their communities and/or District Assembly members, to act as witnesses for survey participants from their community.

Study setting and design

This study was nested within a broader research study of GWL's pro-poor programs, implemented between 2017 and 2023, in the Greater Accra Region, Ghana [27]. 20 areas were selected for household surveys, each area corresponding to one underserved community or a cluster of neighboring underserved communities. 13 of these clusters represented areas where GWL had implemented a pro-poor program, out of 26 GWL program areas in total. These areas were purposively chosen based on three criteria: (1) prioritizing mapped communities with readily available boundary information; (2) ensuring representation from all three of GWL's operating regions in Greater Accra to capture diverse geographies; and (3) including different pro-poor projects (Fig 1). The remaining 7 clusters were purposively selected based on geographic proximity and ethnic/cultural similarity to the 13 program communities, from a separate list of 57 areas identified as underserved communities by GWL's district offices and People's Dialogue Ghana, a community-based non-governmental organization supporting equitable urban development in Ghana. GWL district offices routinely maintain lists of underserved communities based on requests for water service extensions from those communities. Selecting GWL program areas and proximate communities meant that the study population was within GWL's service area, i.e., likely with higher water access levels than communities outside GWL's service area. Additionally, our study areas may represent more politically mobilized communities with the ability to make requests to GWL. Study design and data validation was supported by a Technical Working Group, commissioned by the U.S. Agency for International Development (USAID) -funded program Urban Resilience by Building and Applying New Evidence in Water, Sanitation, and Hygiene project (URBAN WASH) and composed of local WASH policy-makers and practitioners.

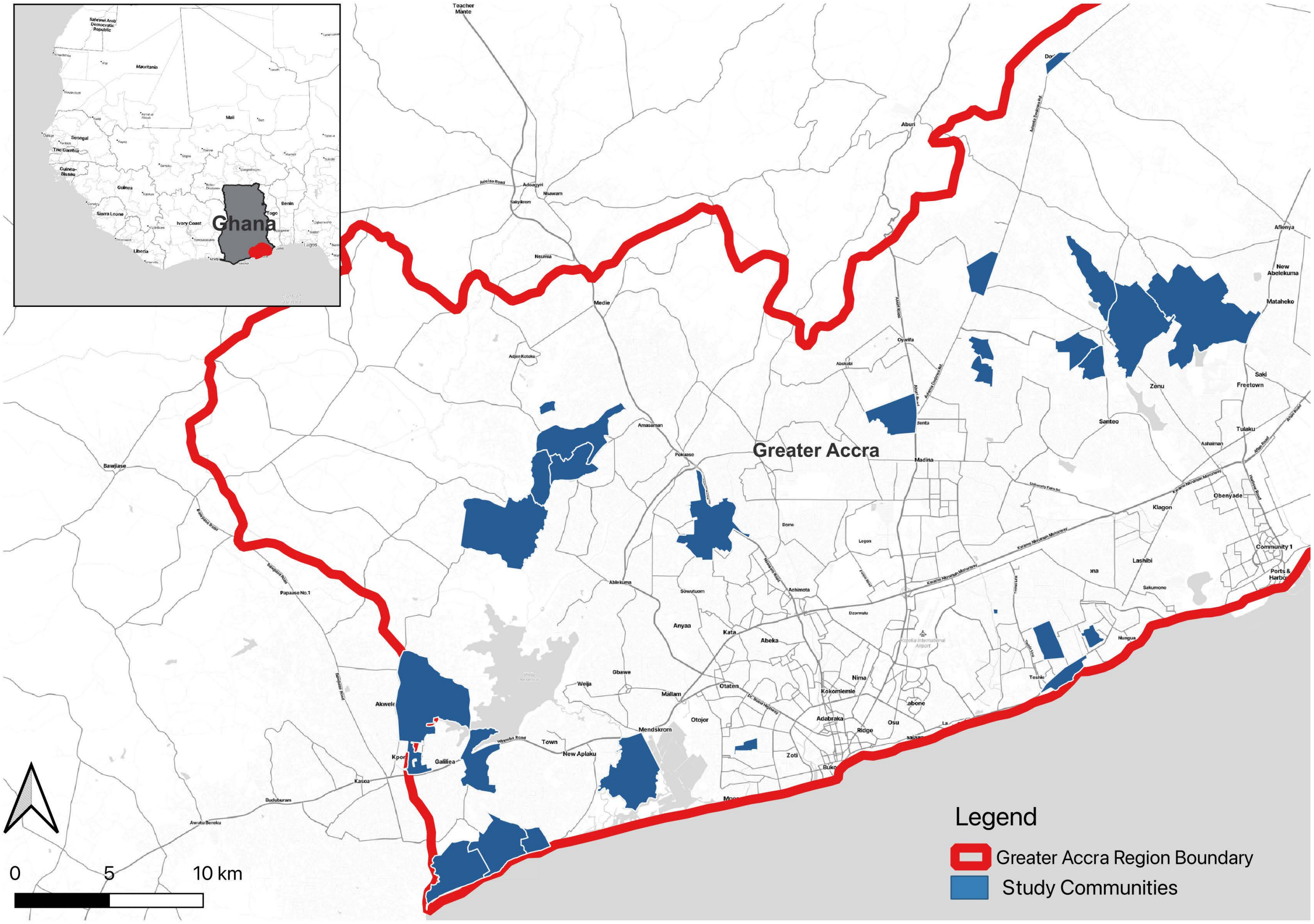

Fig 1. Study areas. Surveyed project communities included Ngleshie Amanfrom, Tetegu, Ofankor, Krokrobite Langma, Tsui Bleo, Obeyeyie/Achiaman/Ayikai Doblo/Doblo Gonno/Ashaladza, Gbestile, Teshie Old Town, Okataban-man, Shukura, Amrahia, Royal City/Agbeshie Laryea, Ashiyie-Fulani, Nungua-Zongo, and My Brother. Surveyed non-project communities included Kubekrom 1, Kubekrom 2, Oshiyie, Rosa Rosa, and Dodowa Zongo. Map tiles by Stamen Design (https://tiles.stadiamaps.com/tiles/), under CC BY 4.0. (https://docs.stadiamaps.com/tilesets/#attribution). Data by OpenStreetMap, under ODbL. Hosted by Stadia Maps.

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We employed a quasi-experimental cross-sectional mixed-methods design, including both quantitative and qualitative data collected simultaneously and analyzed separately (convergent parallel design), for an exploratory evaluation of direct and indirect benefits of piped connections at the household level. We compared outcomes between matched groups of 1) connected and unconnected households (direct benefit); and 2) indirect users and non-users (indirect benefit) [28]. Connected households had access to piped water on premises, either inside the dwelling or in their compound, and may or may not have used piped water as their primary source for drinking or domestic purposes. Indirect users were unconnected households that used their neighbor's piped water, outside their own compound, for drinking and/or domestic purposes. Non-users included unconnected households relying on non-piped sources as well as off-premise piped water, such as public standpipes. We relied on additional qualitative data from focus group discussions (FGDs) and interviews to contextualize findings from the quantitative analysis.

Data collection

Qualitative and quantitative data were collected from July to September 2023. While not designed for this exploratory study, the random, population-representative sampling frame of the evaluation of GWL's pro-poor programs lent itself well to this analysis. Enumerators interviewed adults involved in decision-making using a household survey and entered responses on Android phones using the CommCare survey application. Interviews were conducted in the local language (Twi). Households were randomly selected, aiming for a number of respondents proportional to the total population of each community, as estimated from the WorldPop 2020 United Nations (UN)-adjusted dataset [29]. Household sampling began with random GPS points within the boundaries of each community, which served as daily starting points for enumerators who then selected every eighth household in a randomly generated direction until they reached their target for the day (five household surveys). This approach was chosen to ensure a broad geographic coverage in study communities (Fig A in S1 Text). We confirmed the approach provided adequate spatial coverage while piloting data collection and continued monitoring spatial coverage daily during data collection to advise on potential adjustments. Households were excluded if they were not willing to participate in the study or if no adults involved in financial decision-making were present.

Qualitative focus group discussions and interviews took place in 13 out of 20 study communities. The qualitative interview guides were informed by the larger evaluation of the service provider's pro-poor programs, which this study was nested within. The qualitative interviews focused on understanding successes and challenges with the pro-poor programs from different perspectives (local government, donor, household), and specific barriers for certain vulnerable groups such as women-headed households and renters. Community FGD topics included how individual households learned about the pro-poor programs, their experiences registering for a piped connection, barriers to connecting, reliability of piped water after connecting, piped water in comparison to alternate vendors or water sources and satisfaction with the piped water service provider. A total of 32 focus group discussion participants represented a subset of the randomly selected household survey respondents, with some targeting of specific vulnerable populations such as women and renters. Additional interviews were conducted with community water user associations, local assembly persons (elected officials representing Metropolitan, Municipal, and District Assemblies), and donors of the pro-poor programs. FGDs were conducted in the local language (Twi) by a local graduate student and a community worker contracted by Aquaya. Other interviews were conducted in English by one of the authors (Aquaya). Researchers wrote summary notes during focus group discussions and interviews, which were later translated to English where needed and synthesized. When required, audio recordings supplemented information from written notes to provide further details.

Outcomes

To estimate the benefit of piped connections, the study included household-reported outcomes on water insecurity (IWISE scale), income generation, satisfaction with water sources, use of supplementary water source that is not the primary drinking or domestic water source, cost, availability, storage, time spent fetching water, and expenditure (Table 1). We did not investigate water quality or health outcomes, as this was beyond the sample and budget constraints for this study.

Quantitative analysis

A descriptive analysis compared connected to unconnected households, as well as indirect and non-users of piped water among unconnected households. Sociodemographic characteristics used for household comparisons included: household and compound size, tenancy arrangements, primary sources of drinking and domestic water, sanitation facilities, shared sanitation, head of household sex, head of household age, head of household marital status, head of household education, and custom wealth quintiles relative to Greater Accra. Custom wealth quintiles specific to urban Accra were derived using data from the 2019 Malaria Indicator Survey (MIS) [31] and applying principal component analysis (PCA) to identify

Table 1. Outcomes.

Outcome	Definition
Water insecure	Binary outcome based on crossing the threshold of 4 using the abbreviated 4-item individual water insecurity experiences (IWISE-4) scale [30], which captures the frequency of experiencing worry, change of plans, inability to wash hands, and inability to drink water, due to lack of access to water over the past month.
Household uses water to generate income	Whether any member of the household reported using water to generate income, including for selling water, and preparing food for sale.
Dissatisfied with primary drinking/domestic[1] water source	Whether the household reported being "somewhat not satisfied" or "very not satisfied" with the respective water source.
Use of supplementary water source	Whether the household reported using water from a source other than their primary drinking and/or primary domestic source in the past seven days.
Cost a barrier to using primary drinking/domestic water source	Whether the household reported being unable to use the respective source in the past month due to cost.
Primary domestic source available every day	Whether the household reported their primary domestic water source being available every day. Connected households were asked about water availability from their GWL connection. Data only considered if connected households reported piped water as their primary domestic source. Unconnected households were asked about the availability of their main domestic water source. Question not asked of households that used their neighbor's connection.
Packaged water is primary drinking water source	Whether the household reported using sachet or bottled water as the primary source of drinking water.
Household stores water used for domestic purposes	Whether the household reported practicing any storage of water used for domestic purposes.
Time spent fetching water in past week, in minutes per collector	For each water source, households reported the number of collectors, the number of trips per collector in the past week, and the average amount of time required to walk to the source, queue, fill a container, and walk back.
Household expenditure on water & sanitation, in Ghanaian Cedi (GHS)	Self-reported expenditure on water and sanitation in the past month. Expenditure data on water were collected with one single question capturing overall expenditure, not by source.

[1]Water used for all domestic purposes except drinking, such as cooking, washing, and bathing.

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custom weights for the wealth index computation [32]. We excluded access to water and sanitation from the computation of wealth quintiles, to generate a wealth comparison independent of water and sanitation access [33]. Statistical differences between groups were estimated with chi-square tests for binary and categorical variables, and Wilcoxon rank sum tests for continuous variables.

To prepare the data for the benefits analysis, we created matched samples using coarsened exact matching (CEM) post data collection to balance sociodemographic characteristics between comparison groups [34]. Households were matched based on the following covariates: home ownership (yes; no), household size (1–2; 3–5; 6 + members), head of household age (<35; 35–64; 65 + years), head of household sex (female; male), head of household having high school education or higher (yes; no), head of household marital status (married; non-married), sanitation (not shared; shared; open defecation), and wealth index quintile (poorest; poor; middle; richer; richest) [35,36]. Households with missing matching covariates were excluded from the analysis.

We then used weighted mixed-effect regression models to compare outcomes between matched groups. Specifically, we applied the CEM weights to the models to account for any residual imbalance between matched strata. We used linear models for continuous outcomes and logistic models for binary outcomes. Households with missingness for specific outcomes were excluded from the analysis for that outcome. The models employed mixed effects by using a random effect to control for household clustering at the community level and a fixed effect for the group assignment (connected versus unconnected households; indirect versus non-users). We chose random rather than fixed effects for community, given the large range in the number of households (15 to 415) by community. The analysis of indirect benefits excluded all households with direct access to piped water on premises (i.e., all connected households). Given the exploratory nature of this analysis and the multiple outcomes tested, the analysis included false discovery rate (FDR) adjusted p-values.

To test the sensitivity of our decision to use a matched comparison, we repeated the analyses with two alternative approaches: adjusted and weighted regressions. In the adjusted regressions, all covariates used for matching were instead included as confounders in the regression models. All households in the study sample were included with no weighting. In the weighted regression, households were weighted based on propensity scores generated with the same covariates used for matching. Both the adjusted and weighted regressions controlled for household clustering at the community level with a random intercept. Further sensitivity analyses controlled for community by first restricting matching to within each community and second by including community in the models as a fixed effect instead of a random effect. All analyses were conducted using R statistical software version 4.4.0. [37].

Qualitative analysis

Summary notes from FGDs and KIIs were analyzed for common themes using deductive and inductive coding in Excel. The deductive coding framework was developed using the literature review and research questions designed for the larger evaluation of the service provider's pro-poor programs. Deductive codes for the community FGD included "connection outcomes," "barriers to connection," "alternate vendors," and "reliability of supply." Inductive codes from thematic analysis revealed additional themes such as "piped water intermittency," "piped water quality," and "meter reading complaints." Relevant deductive codes for additional interviews with community leaders, local government officials, and donors included "program successes" and "program challenges".

Results

Descriptive statistics

We visited 2,699 households; 2,521 (93%) were enrolled in the study, 103 (3.8%) were not willing to participate at the time of the visit, and 75 (2.8%) did not have any adults involved in financial decision-making present. Less than half of households owned their own home (45%), and representation was similar across all five custom wealth quintiles (indicating that our study population, despite living in underserved areas, had a similar wealth distribution as Greater Accra as a whole) (Table 2-A). Approximately two-thirds of household heads were male (69%), and most had a high school education or higher (80%) (Table 2-B). Households predominantly used packaged water as their primary source of drinking water (90%), whereas a greater variety of sources were used as the primary domestic water source, including piped water on premises (26%), fetching piped water from the neighbor (22%), and water from tanker trucks (21%) (Table 2-C).

Table 2. Summary characteristics stratified by connected and unconnected households. A) household characteristics; B) head of household characteristics; and C) water source.

	Access to piped water on premises			p-value[1]
A) Household characteristics	**Overall**, N = 2,521	**Yes**, N = 720	**No**, N = 1,801	
Household members, mean (SD)	4.5 (2.4)	4.5 (2.5)	4.6 (2.4)	0.2
Number of additional households in compound, mean (SD)	2.2 (3.6)	2.8 (4.0)	2.0 (3.4)	<0.001
Home owner, n (%)	1,133 (45%)	368 (51%)	765 (42%)	<0.001
DHS Greater Accra wealth quintile, n (%)				<0.001
Q1: Poorest	586 (23%)	41 (5.7%)	545 (30%)	
Q2: Poorer	466 (18%)	97 (13%)	369 (20%)	
Q3: Middle	416 (17%)	132 (18%)	284 (16%)	
Q4: Richer	462 (18%)	168 (23%)	294 (16%)	
Q5: Richest	591 (23%)	282 (39%)	309 (17%)	
B) Head of household characteristics				
Sex, n (%)				0.3
Male	1,727 (69%)	483 (67%)	1,244 (69%)	
Female	794 (31%)	237 (33%)	557 (31%)	
Age in years, mean (SD)	45.7 (13.1)	48.8 (13.5)	44.5 (12.7)	<0.001
Married, n (%)	1,701 (67%)	499 (69%)	1,202 (67%)	0.2
High school education or higher, n (%)	1,914 (80%)	580 (86%)	1,334 (77%)	<0.001
C) Water source				
Primary source of drinking water, n (%)				<0.001
Packaged water	2,278 (90%)	648 (90%)	1,630 (91%)	
Piped to neighbor	80 (3.2%)	1 (0.1%)	79 (4.4%)	
Piped on premises	63 (2.5%)	62 (8.6%)	1 (<0.1%)[2]	
Tanker truck	50 (2.0%)	1 (0.1%)	49 (2.7%)	
Other	50 (2.0%)	8 (1.1%)	42 (2.3%)	
Location of primary drinking water source, n (%)				<0.001
In/delivered to own dwelling or plot	1,612 (64%)	525 (73%)	1,087 (60%)	
In neighbors' compound	530 (21%)	89 (12%)	441 (24%)	
Somewhere else	379 (15%)	106 (15%)	273 (15%)	
Off-premise drinking water source available every day (N = 2,378[3]), n (%)	2,231 (94%)	618 (94%)	1,613 (94%)	0.8
Primary source of domestic water, n (%)				<0.001
Piped on premises	660 (26%)	650 (90%)	10 (0.6%)	
Piped to neighbor	563 (22%)	17 (2.4%)	546 (30%)	
Tanker truck	535 (21%)	22 (3.1%)	513 (28%)	
Protected well or borehole	401 (16%)	7 (1.0%)	394 (22%)	
Public tap/standpipe	146 (5.8%)	5 (0.7%)	141 (7.8%)	
Other	216 (8.6%)	19 (2.6%)	197 (11%)	
Location of primary domestic water source, n (%)				<0.001
In/delivered to own dwelling or plot	1,200 (48%)	692 (96%)	508 (28%)	
In neighbors' compound	1,164 (46%)	21 (2.9%)	1,143 (63%)	
Somewhere else	157 (6.2%)	7 (1.0%)	150 (8.3%)	
Off-premise domestic source available every day (N = 1,194[3]), n (%)	867 (73%)	39 (89%)	828 (72%)	0.015
Main supplementary source (N = 1,062), n (%)				<0.001
Rainwater	860 (81%)	103 (63%)	757 (84%)	
Protected well	62 (5.8%)	18 (11%)	44 (4.9%)	
Packaged water	35 (3.3%)	15 (9.2%)	20 (2.2%)	

(Continued)

Table 2. (Continued)

	Access to piped water on premises			p-value[1]
A) Household characteristics	**Overall**, N = 2,521	**Yes**, N = 720	**No**, N = 1,801	
Piped to neighbor	23 (2.2%)	6 (3.7%)	17 (1.9%)	
Other	82 (7.7%)	21 (13%)	61 (6.8%)	
On-premise piped water available every day (N = 720), n (%)	125 (17%)	125 (17%)		

[1]Wilcoxon rank sum test for continuous variables; Pearson's Chi-squared test for categorical variables with an expected cell count >=5; Fisher's exact test for categorical variables with any expected cell count <5.

[2]One household reported using on-premise piped water even though they reported not having access to piped water.

[3]Data not collected from households that reported using piped water from their neighbor's connection.

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Most off-premise water sources used for domestic purposes were available every day (73%), compared with only 17% on-premise water connections.

Among respondents, 720 (29%) had a piped water connection on premises (Table 1). We found significant demographic differences between connected and unconnected households. Unconnected households shared their compound with fewer additional households (2.0 versus 2.8 on average), had a lower share of homeowners (42% versus 51%), and were poorer, with 50% of unconnected households in the lowest two wealth quintiles compared to 19% of connected households (Table 2-A). Heads of household in unconnected households were younger and less educated (Table 2-B). The vast majority (90%) of connected households used their piped connections as their primary source of domestic water, while unconnected households relied on their neighbor's connection (30%), tanker trucks (28%), protected wells/boreholes (22%), and other sources (Table 2-C).

In the group of 1,801 unconnected households, 563 (31%) were indirect users of piped water (translating to 22% of households in the overall study sample of 2,521 households) by relying on their neighbor's connection (off compound) as either their primary drinking or domestic water source (Table A in S1 Text). The rest of unconnected households (non-users) did not use piped connections; still, most of them (90%) had their primary source of domestic water either on premises (40%) or in their neighbor's compound (50%) (for example, boreholes or water delivered by a tanker truck). Both indirect users and non-users (94% for both) expressed interest in getting a piped water connection on premises. Compared to non-users, indirect users lived in households with fewer household members, in compounds with more households, had a lower share of homeowners, less educated heads of households, but had similar wealth levels to non-users.

Among all surveyed households, only 53% reported that water sources used for domestic purposes were available every day, 42% used additional water sources to supplement their primary drinking and domestic sources, whereas only 14% of respondents were classified as being water insecure (Table 3). A higher proportion of households was dissatisfied with their primary domestic water source (21%) compared to their primary drinking water source (6.4%). Households reported spending on average over 219 GHS on water & sanitation per month (equivalent to approximately 19 USD), and few reported cost as a barrier to using their primary drinking and domestic water sources (12 and 9.2%). A small proportion of households reported using water for income-generating purposes (14%). Water collectors spent approximately 1.5 hours fetching water per week (translating to 1.7 hours per household), driven by water fetching for the primary domestic water source, followed by fetching from supplementary water sources. Two outcomes had missingness for more than a small number of households. Availability of the primary domestic source was missing for 699 households, primarily because it was not collected from households that used their neighbor's connection. Respondents for 74 (3%) households did not know their household's expenditure on water and sanitation.

Table 3. Summary of outcomes.

Binary outcomes	N	n (%)
Use of supplementary water sources	2,518	1,062 (42%)
Dissatisfied with primary domestic water source	2,521	527 (21%)
Water insecure (IWISE)	2,521	345 (14%)
Household uses water to generate income	2,521	357 (14%)
Cost a barrier to using primary drinking water source	2,519	301 (12%)
Cost a barrier to using primary domestic water source	2,521	231 (9.2%)
Dissatisfied with primary drinking water source	2,521	162 (6.4%)
Packaged water is primary drinking water source	2,520	2,278 (90%)
Primary domestic source reported being available daily	1,822	982 (54%)
Household stores water used for domestic purposes	2,521	2,266 (90%)
Continuous outcomes	**N**	**Mean; median (Q1-Q3)**
Time spent fetching in past week, in minutes per collector	2,521	89; 30 (2–92)
Time spent fetching from primary drinking water source	2,521	12; 0 (0–8)
Time spent fetching from primary domestic water source	2,521	53; 14 (0–54)
Time spent fetching from supplementary water sources	2,521	24; 0 (0–0)
Household expenditure on water & sanitation, in GHS	2,457	219[1]; 168 (100–265)

[1]In July 2023 this represented approximately 19 USD.

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Benefits analysis

Matching created 213 strata containing 558 connected households to 950 unconnected households, and 186 strata containing 403 indirect users to 731 non-users, for outcomes with no missingness (Table B in S1 Text). Excluded from matching because of missingness in data for heads of the households (age and education data) were 52 (7%) connected and 103 (6%) unconnected households. Balance was achieved across matching covariates, compared to modest imbalances before matching (overall standardized mean difference before matching of 0.079 and 0.049 for the two comparisons, respectively). The range of matching weights in the control group indicated that some strata contained few control observations requiring substantial weighting to achieve balance.

Compared to unconnected households, matched connected households were less likely to report cost barriers to access their primary domestic source (OR 0.26; 95% CI: 0.14 to 0.48), less likely to use a supplementary water source (OR 0.45; 95% CI: 0.34 to 0.59), and less likely to be dissatisfied with their primary domestic water source (OR 0.65; 95% CI: 0.48 to 0.89) (Fig 2A and Table C in S1 Text, where p-values and FDR-adjusted p-values are additionally provided). However, connected households were also less likely to report their primary domestic water source being available every day (OR 0.12; 95% CI: 0.09 to 0.18) compared to non-users. We did not collect this data among indirect users.

Water collectors in connected households spent an average of 61 minutes (95% CI: 84–38 minutes) less time fetching water in the past week. This translates to an average 61% time savings (40 minutes time spent on average among collectors in connected households and 101 minutes among collectors in unconnected households) and a median difference of 30 minutes. This was driven primarily by time savings from non-drinking domestic sources (33 minutes; 95% CI: 45–21 minutes). The time savings per collector was not related to connected households having more collectors. Connected households had 1.4 water collectors on average compared to 1.7 for unconnected households. Our analysis did not identify any statistically significant differences between connected and unconnected households regarding the following factors: packaged water being the primary source of drinking water, cost being a barrier for the primary drinking water source, dissatisfaction with the primary drinking water source, water insecurity, water storage, and income generation (Fig 2A).

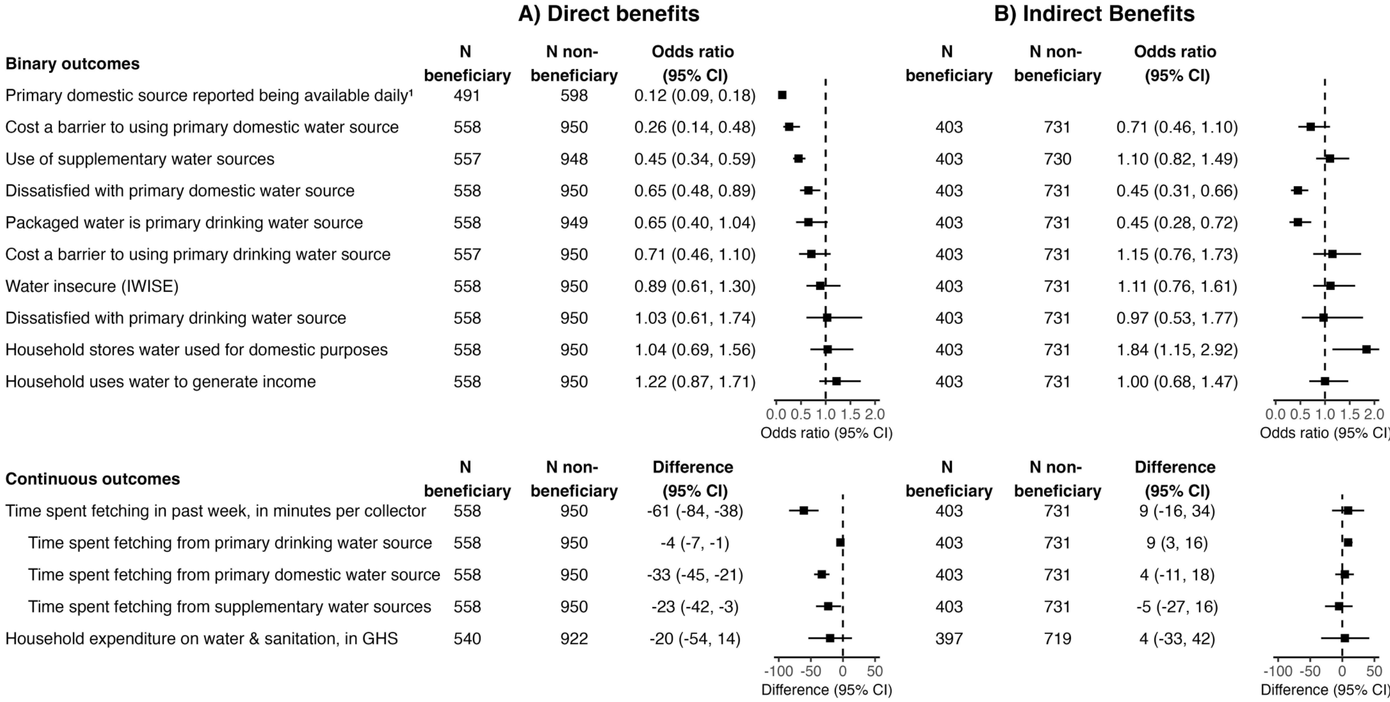

Fig 2. Benefits. A) Direct benefits: comparing connected and unconnected households; **B)** Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users). [1]Data not collected from households that used their neighbor's connection (i.e., indirect users). In the direct benefits column, the odds ratio for this outcome thus compares connected households to households that did not use piped connections (i.e., non-users). For indirect benefits, this outcome was not estimable.

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Compared to non-users, indirect users were less likely to be dissatisfied with their primary domestic water source (OR 0.45; 95% CI: 0.31 to 0.66), less likely to use packaged water as their primary drinking water source (OR 0.45; 95% CI 0.31 to 0.72), and more likely to store water used for domestic purposes (OR 1.84; 95% CI: 1.15 to 2.92) (Fig 2B). We saw no other statistically significant differences between indirect and non-users.

Sensitivity analyses showed that the directionality of associations was similar when using adjusted or weighted regressions instead of matching (Fig B in S1 Text and Fig C in S1 Text). For propensity score weighting, good balance was achieved for both comparisons (Table D in S1 Text and Fig D in S1 Text). However, confidence intervals were narrower for most outcomes with the alternative analytical approaches, resulting in more statistically significant differences. For example, connected households were less likely to drink packaged water compared to unconnected households in both the adjusted (OR 0.59; 95% CI 0.40 to 0.87) and weighted (OR 0.71; 95% CI 0.57 to 0.88) regressions. Further, the findings were not sensitive to how the analysis controlled for community. The directionality and magnitude of associations were similar when the analytical sample was restricted to matching within the same community (Fig E in S1 Text) and when the models controlled for community as a fixed effect instead of a random effect (Fig F in S1 Text).

Qualitative findings

Focus group discussions provided insights into households' preference for drinking packaged water. Respondents shared concerns with the quality of piped water, such as chemicals from farmlands polluting a nearby dam, gutters "leaking" into the piped water, and observations of "impurities" in the piped water when it restarted after a period of unavailability (though none of these statements were independently verified during the study). Some respondents also shared concerns with borehole water being salty or unclean if too shallow. With tanker trucks, the main concern was that one could not be certain about the original source of their water. Perceived water quality was thus presumably a key driver of households' preference for packaged water, though respondents also noted this was the most expensive option.

Focus group discussions also showed that residents viewed time savings as one of the main benefits of piped connections. A respondent stated that even 10 minutes saved on fetching would make it worth getting a piped connection. Barriers to getting a connection included cost (both the lump-sum connection fee and the apprehension of future water bills), lack of information (some respondents did not know the connection fee amount), lack of installment payment options, and tenancy status. Renters reported that landlords were unwilling to pay the connection fee and either asked the renter to pay, or in one case, asked the renter to leave the property if they were not satisfied staying without a connection. Renters were generally unwilling to pay the connection fee, as they did not want to invest in an asset they could lose access to in the case that they moved away and expressed frustration at landlords' failure to fulfill their responsibility.

Connected households reported that piped water was highly intermittent and not always predictable (i.e., supply did not follow a set schedule), causing them to rely on storage when possible. Reports of low pressure added to the challenges and respondents complained that it took a long time to fill large storage containers such as polytanks. Alternative water sources like tanker trucks and boreholes were perceived as more reliable (i.e., water was available when needed).

Discussion

This observational study used controlled comparisons to explore the direct and indirect effects of piped water connections in Accra's underserved communities. Our findings provide a nuanced picture of the service levels and household water practices associated with the expansion of piped networks in these settings.

Less than one third of households had a piped connection on premises. These households were more satisfied with their domestic water source, less likely to use supplementary water sources, and water collectors saved approximately one hour per week fetching water compared to unconnected households. These results indicate that piped water connections make everyday life more convenient and allow households to save time, consistent with existing literature [38–40]. Given the highly gendered nature of water fetching responsibilities [41], these improvements likely benefit women, potentially reducing gender disparities [42,43], increasing productivity, and promoting psychosocial wellbeing [44]. Other studies documenting time savings found larger gains, such as 3.8 hours per week in rural Zambia [45], and 0.9-1.8 hours per day in rural Ghana, Zambia, and India [46]. Smaller time savings in urban contexts, such as Accra, are not surprising due to the higher spatial density of alternative water sources compared to rural areas.

Connected households were less likely than unconnected households to report cost barriers to access their primary domestic source, suggesting fewer affordability challenges. We however found no statistically significant reduction in water and sanitation expenditures (lower expenditures detected in sensitivity analyses, but not in the matched comparison, possibly as a result of the lower sample size in the latter). We note that more affordable water may not necessarily result in reduced expenditures if households consume larger volumes of water. This study did not collect data on consumption volumes, but other evidence suggests that gaining access to piped water on premises could lead to a 20–40% increase in water consumption [45,46]. Data on consumption volume are not readily available in the literature for this context, with evidence from Accra focused primarily on household expenditure on water, stratified by source type, but without contextual consumption volume data [47,48].

With respect to water availability, results were more nuanced. Only 17% of connected households reported that piped water was available every day. Compared to non-piped users, connected households thus experienced less availability of their primary domestic water source. This likely explains why they were equally likely to store their domestic water, despite the source being closer. Overall, about 90% of households stored their domestic water, a widespread practice unaffected by piped connections in this context. We also found no reduction in perceived water insecurity when comparing connected and unconnected households, as measured by the 4-point water insecurity (IWISE) scale with a binary outcome. This may be because water insecurity was low overall (14%), limiting opportunities to detect reductions. It may also be due to limitations with the IWISE outcome metric, which aggregates experiences over a 12-month period, whereas water-related stress likely varies seasonally [49]. The metric also excludes additional dimensions of water insecurity such as perceived water contamination and reliance on multiple sources, which may provide different insights [50].

A piped connection on premises may allow a household to initiate or expand an income-generating activity requiring water. In rural Zambia, for example, a study found that connected households boosted garden cultivation and generated additional income [45]. Another study found that connected households were more likely to sell food and beverages in rural Ghana and more likely to rear livestock in rural India [46]. In contrast, we found no increase in income-generating activities among connected households in Accra. However, according to members of the Technical Working Group who provided their interpretations based on local knowledge, respondents may have underreported income-generating activities for fear of being charged commercial water tariffs rather than residential tariffs. The tariff structure could be a real deterrent with "non-residential" and "commercial" customers being charged roughly 1.7 and 3 times the domestic (non lifeline) volumetric tariff respectively, in addition to double the flat service charge [51]. Note that Ghana Water and the national regulatory body do not provide a written description of requirements to fall into the non-residential or commercial categories, and small businesses may fall in either. Overall, only 14% of respondents reported using water for income-generating purposes.

Most households in the study area (90%) primarily drank packaged water, with no clear indication that this practice declined among connected households. While connected households were less likely to drink packaged water in sensitivity analyses, the difference was not statistically significant in the matched comparison. Packaged water, primarily in the form of sachets (i.e., water sealed in plastic bags), is also common in other parts of the country (except northern regions) and trending up [52], potentially reflecting cultural aspirations independent of piped water access.

The increased reliance on packaged water does not rule out potential health impacts from piped water connections. Beyond drinking water, health benefits may arise from other pathways such as use of piped water for cooking, more frequent hand washing, cleaner sanitation facilities [53,54], and reduced risks of injury during water fetching [55]. In fact, a systematic review suggested that on-premise water access may curtail water-washed (hygiene-related) diseases even more than waterborne diseases [56].

Approximately 22% of households in our study areas used piped water through their neighbor's connections, i.e., indirectly. Compared to non-users (i.e., households relying on boreholes or tanker trucks), these indirect users were more satisfied with their primary domestic water source, but equally likely to require supplementary sources and more likely to store water. Importantly, we found no evidence of time savings for indirect users. Overall, benefits for indirect users were limited, and 94% mentioned wanting their own piped connection.

These findings contrast with other studies. In rural Ghana and Zambia, relying on a neighbor's piped connection allowed households to save time as compared to using non-piped community water points (though the time savings for these indirect users were less pronounced than among connected households) [46]. Another study in Maputo, Mozambique reported time and cost savings among the urban poor that used their neighbor's connection instead of a public standpipe [57]. In this study, the lack of time savings and unchanged reliance on supplementary sources among indirect users indicates that a neighbor's connection was not more convenient, close by, or accessible than alternative sources. In fact, the majority of the alternative non-piped sources were located on premises or in a neighbor's plot. Additionally, connected households tended to lock their taps to regulate neighbors using them, likely reducing accessibility and convenience for indirect users. Overall, our findings add to the limited body of literature on the indirect impacts of water and sanitation interventions in urban settings, which have shown spillover effects on water quality and health in other settings [58,59].

Implementers of piped water expansion programs sometimes optimistically assume that one piped connection will benefit many more households (up to 30, according to our key informant interviews). This study shows that these assumptions are unrealistic in Accra. First, the ratio of indirect beneficiaries to direct beneficiaries was only around 1:1 in our study areas (not 30:1). Second, we found that indirect users derived limited benefits, with no evidence of time savings or reduced reliance on supplementary water sources. These findings provide a strong justification for expanding piped connections to as many households as possible, ideally all. This is especially critical from an equity standpoint, as indirect users tend to be poorer than direct beneficiaries. In this study sample, 53% of indirect users were in the two poorest wealth quintiles compared to 19% of connected households. Connecting everyone will not only require strategies to make upfront connection fees more affordable (e.g., through subsidies or installment payments), but also strategies to connect renters. Additional research is needed in these areas to best guide service providers in their efforts to leave no one behind.

When interpreting the results of this study, its limitations should be considered. First, the study was nested in an evaluation that was not specifically designed to quantify the direct and indirect benefits of piped water. Given the exploratory nature of the study and number of outcomes examined, findings should be interpreted with caution because of the potential for Type I error (i.e., incorrectly rejecting the null hypothesis). We attempted to address this limitation by providing FDR-adjusted p-values. To explore potential direct and indirect benefits of piped water, we employed a quasi-experimental approach using coarsened exact matching. This approach cannot establish causality. Evaluating the effects of water infrastructure provisions using a gold-standard randomized controlled trial is often impractical, because of the difficulty of randomizing households to the intervention due to planning and engineering considerations [60]. We chose a quasi-experimental approach to control for potential confounding by balancing comparison groups, and thus reduce the sensitivity of our findings to household types that are not proportionately represented between groups [61]. As a result, matching reduced the number of households available for the direct and indirect benefits analyses, which can lead to reduced analytical power [62]. This was confirmed by findings from the sensitivity analyses, which suggested consistency in the directionality of point estimates regardless of analytical methods used, but narrower confidence intervals for several outcomes in both the adjusted and weighted regressions. Of all the methods employed, the matched comparison presented in the main text had the most conservative results. In the primary and sensitivity analyses, there may have been additional unmeasured confounders we were not able to control for. An additional limitation was that sampling for this research was not designed considering analytical power for an analysis of direct and indirect benefits of on-premise piped water. As a result, we may not have been powered to detect statistical differences for select outcomes, which, in concert with the loss of power resulting from matching, suggests that direct and indirect benefits of piped water could extend beyond those outlined in the primary analysis. We were also limited by a select number of outcomes of the larger research study to quantify benefits of piped water and did not estimate impacts on other outcomes, including physical health outcomes and psychosocial wellbeing. For the outcome on daily availability of the primary domestic source, the control group in the direct benefits analysis did not include households using their neighbor's connections due to missing data, likely resulting in higher availability in the control group than if they had been included. Further, this outcome may have been prone to reporting bias among connected households, who may more readily notice outages in the water supply and thus report less daily availability. Taken together, we expect the effect estimate for availability to be biased away from the null.

Conclusions

Expanding piped connections in underserved communities is a requirement for achieving the Government of Ghana's ambitious goals towards universal access to safely-managed water services [63]. While the challenges of expanding access to piped connections in low-income settings have been well documented [64] (including administrative barriers [65], additional fees and costs imposed on households [66], and the time it takes to get a connection [21]), this study contributes important evidence on the direct benefits to connected households as well as the limited indirect benefits to households that use their neighbor's connection. We found that direct benefits were more pronounced in the form of convenience (water source on premises, lower need for supplementary sources), time savings, higher satisfaction, and affordability. These benefits could contribute to the broader wellbeing of individuals, particularly through redirecting time savings into income generating activities, household chores (e.g., food preparation) or leisure [19,67]. These findings, combined with national goals to reduce inequities in water access, justify lowering entry barriers for low-income households, such as reducing the upfront connection fee.

While this study focused on the first criteria of safely managed water services (i.e., located on premises) future research may expand on it to incorporate the benefits associated with the other two criteria - free from contamination and available when needed. Even though piped water is not a primary source of drinking water for most households in Accra due to the widespread use of packaged water, it is used for cooking and bathing, and may still be ingested. It also serves as drinking water for some of the most vulnerable households who cannot afford packaged water, reiterating the need to ensure sufficient water treatment. Reducing intermittency of piped water services requires equal attention and would help maximize the benefits of these investments. Only 17% of piped connections in our study areas provided water every day, which may result from planned rationing, power outages, and/or low pipe pressure due to other reasons such as leaks or consumption exceeding the volume of water available. Diligent water resources management, potential investments in production capacity, and proactive maintenance of existing distribution infrastructure are needed in parallel to expanding connections [68].

Supporting information

S1 Text. Table A. Summary characteristics stratified among unconnected households. A) household characteristics; B) head of household characteristics; and C) water source. Table B. Balance table. Coarsened exact matching. Table C. Benefits. A) Direct benefits: comparing connected and unconnected households; B) Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users). Table D. Balance table. Propensity score weighting. Fig A. Household sampling geographic coverage. Example from three study communities. Fig B. Sensitivity analysis using adjusted regressions. A) Direct benefits: comparing connected and unconnected households; B) Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users). Fig C. Sensitivity analysis using weighted regressions. A) Direct benefits: comparing connected and unconnected households; B) Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users). Fig D. Overlap plots. Propensity scores. Fig F. Sensitivity analysis matching on community. A) Direct benefits: comparing connected and unconnected households; B) Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users). Fig E. Sensitivity analysis with community as a fixed effect. A) Direct benefits: comparing connected and unconnected households; B) Indirect benefits: comparing households relying on their neighbor's connection (indirect users) and households that do not use piped connections (non-users).
(DOCX)

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