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The Effects of Tap Water Outages on Household Income, Unemployment, and Women's Labor in Panama[†]

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Abstract

Inadequate access to clean tap water restrains individuals' ability to engage in productive activities and generate income. When tap water provision is interrupted, people must dedicate considerable time to fetching water and managing its use for household chores, while facing significant health risks due to reduced hands and food washing.

Using repeated cross-sectional data from 32,652 households and 44,178 individuals aged 18 to 56 from the Multipurpose Surveys of Panama for the years 2017, 2018, and 2019, we find compelling evidence that increasing hours of tap water outage (due to infrastructure inefficiencies) reduce household income, increase the likelihood of unemployment, and decrease the hours female workers can dedicate to productive activities.

Previous studies highlight that transitioning from not having tap water to having it positively affects socio-economic development, especially in middle- and low-income countries. However, beyond the initial provision of tap water, we provide evidence of the importance of continuous maintenance and investment in water infrastructure, as old pipelines, inadequate water treatment facilities, and insufficient distribution networks are the main causes of jeopardized water quality and supply reliability in many developing countries.

Keywords: Tap water, Outage, Water infrastructure, Household income, Unemployment, Gender roles

JEL classification: O10, O18, Q01, Q25, Q56

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1. Introduction

Rapid urbanization and increasing droughts are intensifying water scarcity globally (Cremades et al., 2021). Despite Latin America's abundant water resources, producing significantly more water flow per unit of land area in comparison to other regions (Bretas et al., 2020). Many developing countries such as Panama, face challenges in achieving UN Sustainable Development Goal 6: "Clean Water and Sanitation for All." Uneven water distribution, disorganized urbanization, inadequate infrastructure, weak governance, and insufficient investments create water security issues. In 2023, Panama's National Statistics Institute showed that around 25% of residents experienced water supply interruptions, raising questions about the consequences of these recurrent tap water inefficiencies.

This paper investigates how hours of weekly tap water outages affect three fundamental socio-economic measures: (1) total monthly household income, (2) the probability of unemployment among economically active individuals, and (3) the working hours of employed individuals, with a focus on comparing the allocation of productive hours between male and female workers. Moreover, we consider the role of higher education and the householder's age in response to the impact of water outages. To address these issues, we use data from Panama's Multipurpose Surveys, which provide repeated cross-sectional information for 2017, 2018, and 2019, encompassing 32,652 households, 44,178 economically active individuals, and 41,437 workers from all provinces and Comarcas (Indigenous areas) in Panama.

Our results indicate that a one-hour increase in water outages per week can lead to a 0.07% reduction in monthly household income. Furthermore, we find that highly educated and older householders have less negative impact from water outages since they can employ more effective coping strategies. We also observe that unemployment probabilities increase with water outages, with women being the most negatively affected. These gender differences are also observed for weekly working hours, where female workers decrease the time allocation for productive activities by 26.8 seconds per hour of outage. This corresponds to a reduction of more than 35 minutes per week for those experiencing over 80 hours of outage, a common scenario for 24% of households in our analysis.

We provide evidence that interruptions in tap water service have significant implications for the well-being of individuals. Household members may need to dedicate additional time to managing limited water quantity for household chores and traveling to collect water from other areas, or they may be more prone to illness due to the inability to wash hands and food frequently. These disruptions limit their labor market participation in addition to their overall contribution to household income.

These mechanisms have been explored by the previous literature, generally analyzing the effects of water access on allowing individuals to allocate more time to productive activities and mitigate risks associated with inadequate sanitary practices. For instance, Meeks (2017) and Zhang (2012) demonstrate that access to clean water reduces time spent on chores, illness rates, and even infant mortality. When understanding the impact on female labor participation, Li et al. (2024) found increased employment for both genders in rural China with better water access. In rural Pakistan, improvements in water infrastructure allow women to participate more in productive and leisure activities (Ilahi and Grimard, 2000), while Koolwal and Van de Walle (2013) observed no such effect across other regions. This clarifies that cultural, infrastructural, and environmental differences must be considered, with studies on on-site water suggesting that time-saved fetching water can allow women to engage in more productive activities or reduce their agricultural workload, depending on the specific region and climate factors (Irianti and Prasetyoputra, 2019; Sedai, 2021). Furthermore, Cook et al. (2024) use an experimental study to understand the behavioral response of households to safe drinking water accessibility in rural Kenya, where 120 minutes of water collection per day were relocated to

other household work, leisure, and socializing. Gross et al. (2018) present that new water collection points save households an average of 41 minutes each day in rural Benin.

Existing research at the country and municipality level also explores how inadequate infrastructure maintenance can lead to water contamination, health issues, and economic disruptions (Ashraf et al., 2021; Bhalotra et al., 2021). Beyond these visitable repercussions, the absence of adequate water supply not only poses challenges in terms of time constraints but also manifests documented consequences from a mental health perspective, as studies indicate that service inequalities and the absence of safe water are significant psychosocial stressors (Toivettula et al., 2023).

Although previous studies discuss the benefits of enhanced water provision, they mainly focus on collection water points, or the transition to having tap water in their premises. Meanwhile, those studying pipe system infrastructure limit their analysis to country, municipal, or community level, therefore our setting aims to fill this gap by measuring household and individual information and focusing on households that reported already having access to tap water. Since many developing countries have achieved a high rate of the initial provision of tap water, this study contributes to the generation of policies on updating and proper maintenance of tap water systems. Moreover, to the best of our knowledge, we are the first to consider the role of education and age in coping with tap water outages.

The rest of this paper is organized as follows: Section 2 provides the background and previous literature, Section 3 discusses the methodology and data, Section 4 presents our results, and Section 5 concludes and provides some policy recommendations.

2. Background and Previous Literature

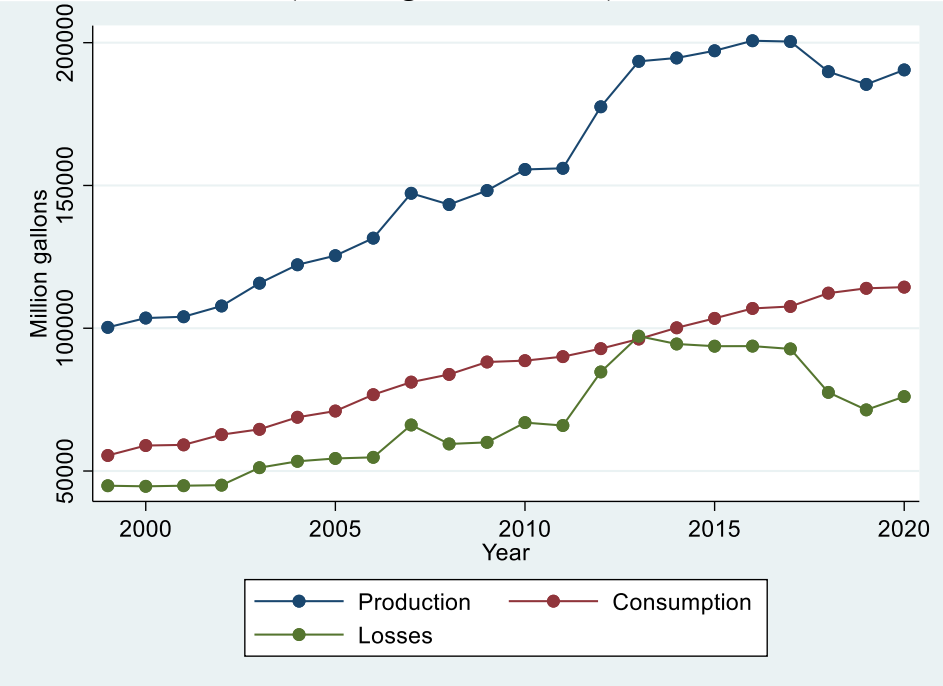
Despite Panama ranking fifth in average depth of annual precipitation worldwide, it faces critical challenges in water management and utilization. The Inter-American Development Bank (2020) reports that 507 liters of water per capita are consumed daily, which exceeds the global average by more than 2.5 times. This figure would position Panama as the fourth-highest consumer globally and the leader in Latin America. However, water revenue estimations suggest an actual consumption of only 280 liters per capita, indicating that approximately 40% of produced water is wasted. As Figure 1 shows, potable water production has increased since 1999; however, consumption levels remain relatively low. This discrepancy is mainly attributed to deficiencies in infrastructure maintenance, management, and investment.

National statistics provide varied insights into tap water access in Panama. While the 2023 National Population and Household Census reports 93% of households with tap water, a closer look reveals relevant limitations. Only 75% of households enjoy uninterrupted tap water provision during the dry season, which marginally increases to 80% during the rainy season. These households are served by two provision systems: water treatment plants and rural aqueducts, divided into public and private administration. Water treatment plants are overseen by the National Institute of Aqueducts and Sewers of Panama (Instituto de Acueductos y Alcantarillados Nacionales, IDAAN), primarily serving areas with more than 1,500 inhabitants. Of the population served by IDAAN, 71% have water meters, but only 24% of those meters are read[3], which limits their capacity to target the exact locations and causes of water loss. Conversely, the Ministry of Environment of Panama (MiAmbiente) regulates all rural aqueducts, which serve communities with less than 1500 inhabitants that do not have infrastructure access to water treatment plant services. Both systems, water treatment plants, and rural aqueducts, face challenges in terms of their capacity and rapidly increasing demand.

[3] Anecdotal evidence is obtained from a national newspaper article: https://www.laestrella.com.pa/panama/nacional/idaan-facturara-consumo-base-registro-CELE490398 reveals that IDAAN hired the company Sigma for 5 years, starting in January 2023, to improve the water metering and charging systems.

Authorities and the media recognize these deficiencies, but research on their socio-economic consequences remains scarce. This situation raises key questions: How does inconsistent tap water access limit Panamanian households' income generation? Furthermore, how does it shape the participation of economically active individuals in the labor market? Our research aims to bridge this gap by examining the impacts of infrequent tap water provision in Panama.

Figure 1. Panama's water treatment plants' production, consumption, and losses. (Million gallons of water)



Note: Figure constructed using data from the Autoridad Nacional de los Servicios Públicos (National Authority of Public Services), IDAAN's volume of water produced and consumed from 1999 to 2020.

Building on existing literature, we highlight the multidimensional benefits of water access in developing economies. Meeks (2017) shows that improvements in water technologies in Kyrgyzstan reduced household distance to tap water sources and the time intensity of household chores, resulting in productivity gains. Additionally, Zhang (2012) found that the introduction of village-level access to water from water plants reduced illness incidence in adults by 11%; correspondingly, Fan and He (2023) demonstrated that the provision of piped water significantly decreased infant mortality, with a ten-percentage point increase in piped water coverage leading to a fifteen-percentage reduction in infant mortality. Frempong et al. (2021) combined administrative information on water supply with household socio-economic panel data from Uganda and discussed that improved water sources per capita do not appear to have a statistically significant effect on the likelihood of individuals suffering from symptoms of illness associated with the inefficient water supply at the sub-county level. In contrast, Devoto et al. (2012) show that households are willing to pay on credit for a private connection in urban Morocco, not necessarily because of health improvements but because it increases the time available for leisure and reduces conflicts among household members on water matters, which leads to overall well-being.

We emphasize the importance of tap water access on time allocation as previous studies have widely discussed their relationship. Cook et al. (2024) implemented an experimental study in rural Kenya, using short surveys (n=9,201) completed by 222 respondents several times each day over 6 weeks, where they found that reducing 120 minutes of water collection per day

resulted in respondents reallocating approximately half to other household work and half to leisure and socializing. While their nonexperimental, high-frequency evidence suggests that water collection is associated with having less energy and more physical pain. Similarly, studies using a difference-in-difference approach show the implications of the adequate implementation of the improvements in access to tap water. Pickbourn et al. (2022) show how in Uganda aid-funded WASH projects increase household access to improved sources of water, however, households may also allocate more time to water collection, as they need to travel longer distances and experience longer wait times due to congestion at water service points. Contributing to this, Gross et al. (2018) provide evidence that in rural Benin new water points can reduce congestion at collection places and save households an average of 41 minutes per day. It has also been demonstrated that to achieve the positive benefits of clean water it is necessary to increase social influence and reinforce information since individuals might not be aware of the importance of clean water and its socio-economic effects (Nelson-Nuñez et al., 2022). In addition, increasing water accessibility can have an unexpected negative effect on households as it can decrease the probability of disinfection or purification of their drinking water, ignoring the presence of pollutants such as E.coli (Gross et al., 2022).

Our research delves deeper into the complex relationship between water access, income levels, and gender roles. Winter et al. (2021) reveals that households, especially women, with access to piped water in rural areas of sub-Saharan Africa reported better well-being and more time to engage in productive activities inside and outside their houses which is also observed in rural Pakistan with improvements in water supply infrastructure (Ilahi and Grimard, 2000). Li et al. (2024) analyzed the impact of enhanced water access in rural China, revealing a significant increase in off-farm employment and income growth and emphasizing nearly identical positive effects on off-farm employment for both genders. In contrast, Koolwal and Van de Walle (2013) found no evidence linking improved water access to increased off-farm market-based work for women across various African, Middle Eastern, and South Asian countries. However, their results and those discussed by Irianti & Prasetyoputra (2019) and Sedai (2021) argue that providing direct access to on-premises tap water sources can reduce the time spent fetching water, thereby allowing women more labor time and decreasing women's involvement in agricultural production in specific regions. Moreover, as climate change is projected to increase drought periods, Fonjong & Zama (2023) highlight how these events can intensify rural female labor in Cameroon due to their effect on water availability. Interestingly, Shimamura et al. (2022) found that girls who live near boreholes can significantly decrease the time spent on schooling and homework and increase the time spent on water-related household chores including fetching water, because of shifting the burden from adult women to girls.

The former studies offer a picture of tap water accessibility and its different outcomes; nonetheless, they focus on the initial transition to water access or the proximity to water collection points, which overlooks the consequences of insufficient maintenance and investment in tap water supply systems. Further studies involving tap water outages demonstrate how reduced rainfall has negative implications on economic growth (Distefano and Kelly, 2017). In addition, it is found that unreliable water systems infrastructure combined with drought events contribute to higher water outages, resulting in significant losses in annual sales of firms in low or lower-middle-income economies (Islam and Hyland, 2019). Similarly, Iimi (2011) provides evidence of the impacts of water supply infrastructure with longer water supply suspensions significantly increasing firms' operating costs in Eastern Europe and Central Asia.

Damaged pipes and breaches can also contaminate clean water and cause inconsistent water pressure, undermining the effectiveness of chlorination, which is essential for ensuring safe drinking water (Lee and Schwab, 2005; Ngben and Yakubu, 2023). Similarly, Okurut et al.

(2023) show how continuous water supply and pressure reduce turbidity, the presence of solids, and apparent color in the water, preserving quality levels. Consequently, if infrastructure problems exist, they can lead to significant health impacts, notably reducing the efficacy of efforts to lower childhood diarrhea mortality rates (Bhalotra et al., 2021). Furthermore, Ashraf et al. (2021) indicate that an increase in water outages reduces handwashing, which results in a rise in waterborne illnesses. They also discuss that these disruptions in water supply led to a loss of economic activity and a distortion in the time-use patterns of young women in Zambia. In the same way, Stoler et al. (2012) reveal that infrequent tap water supply in Ghana represents significant health risks for poor women and children; however, the consumption of water sachet can help mitigate these deficiencies. Moreover, Russ (2020) explains how water deficits, measured by negative runoff shocks, significantly diminish the economic activity of middle-income countries and regions.

In summary, although previous literature provides relevant bases for understanding the impact of tap water inefficiencies, most of it relies on firms, districts, or country-level data sources. It focuses on sudden water supply interruptions rather than consistent tap water provision patterns. Therefore, our research aims to fill this gap by examining the implications of inconsistent water provision on the socio-economic development of households in Panama. We use households' self-reported hours of tap water to minimize measurement errors, capture exact variations, and provide robust reliable results. To the best of our knowledge, it is the first study to econometrically analyze how hours of tap water outage affect the socio-economic characteristics of multiple households and individuals while considering the heterogeneity of education levels. Additionally, we provide valuable evidence of the effects of recurrent weekly tap water outages on women's time allocation constraints in the labor market.

3. Methodology and Data

3.1 Methodology

The purpose of this analysis is to explore the impact of weekly hours of tap water outages on households' income, the unemployment probabilities of individuals, and the working hours of employed people. Thus, we estimate the following model:

$$Y_{irt} = \beta_1 HW_i + \gamma X_i + \theta_r + D_t + u_{irt} \quad (1)$$

Where Y_{irt} is the outcome variable in province *r* in year *t*, encompassing either the real household income, an indicator equal to one if a person in the workforce between the ages of 18 and 56 reported being unemployed, or in the case of employed people, the number of hours they work in a week. HW_i denotes the self-reported total weekly hours of tap water outages[4]. X_i includes characteristics of the household and individuals, such as the householder's age, if female or not, if having more than 15 years of education or not, household size, number of underage members, if living in an urban area or not, the type of water provision system they use, and if having access to garbage collection or not. θ_r represents province-fixed effects that control for time-invariant characteristics, D_t accounts for year-fixed effects, controlling for time-varying factors such as national policies, environmental conditions, and economic shocks, and u_{irt} is the error term. When estimating the effects on household income, we include zero-valued observations by transforming the income using the Inverse Hyperbolic Sine (IHS).

[4] The use of self-reported data allows us to account only for the hours during which households do not receive tap water when they need it. Therefore, if households do not receive tap water while they are sleeping or not at home, this may not be reported in the survey since they might be unaware of it.

We further examine the heterogeneous effect of hours of tap water outages by adding an interaction term of education level or householder age groups with HW_i. This allows us to understand how the impact of water outages differs depending on whether individuals are highly educated or not, which can shape the mechanisms and strategies households and individuals use to respond to water outages. Householder age groups demonstrate how experience and acquired abilities over time also influence the response to the effects of water outages.

To deepen our investigation into the impact of tap water hours on women's unemployment and work allocation time, we subset individuals' data based on their gender. This approach enables us to assess whether the effect of tap water hours on unemployment and working hours varies between economically active male and female workers.

3.2 Data

Household and Individual Data

The data used in this study are obtained from the Multipurpose Surveys of Panama (Encuestas de Propósitos Múltiples), collected and administered by Panama's National Institute of Statistics and Census (Instituto Nacional de Estadística y Censo, INEC)[5]. These surveys provide repeated cross-sectional data for households and individuals from 2017 to 2019, including the information on weekly hours of tap water received by households. The survey is conducted over approximately one month and takes place annually from the middle of March, which marks the end of the dry season[6]. It provides the location of households at the province level as the most precise geographic detail.

The variations in hours of water outage are constructed by subtracting the reported weekly hours of tap water from 168, which is the total hours a house is served if receiving the service 24 hours, seven days a week. Descriptive statistics in Table 1 show that the average hours of outage household experience are around 34. There is the possibility that households with higher income levels could choose to live in areas with better infrastructure, which could make the hours of tap water endogenous. Nevertheless, we argue that limiting observations to those already connected to tap water provision systems ensures a similar baseline level of infrastructure access for all households. Moreover, the inclusion of regional characteristics that might influence the decision of households to move to a place with better infrastructure, such as urban areas, water provision systems (water treatment plants, public or private rural aqueducts), access to garbage collection services, and province fixed effects, helps to reduce the possibility correlation between our variable of interest and the error term. More importantly, the fluctuations in the provision of tap water in Panama are mainly attributable to unpredictable supply factors, such as infrastructure performance and deteriorations and delays in the reparations of piped systems. Therefore, households do not have direct control over the exact hours they receive tap water.

Information about individuals reveals that 6% of economically active individuals reported being unemployed, and the average time employed people dedicate to working is 38.2 hours a week, which is around 7 and 30 minutes in 5 days; this is a common scenario, especially for public servants in the country. Additionally, we include the number of underage members in the households due to the cultural aspect of Panamanian households, where women mostly take care of children, which could influence the hours women dedicate to productive activities.

[5] The microdata that supports the findings of this study are available under formal, written request and permission from INEC at https://www.inec.gob.pa/contacto.

[6] The use of this dataset offers us the advantage of analyzing the effects of water outages during the dry season, which is also the period with the highest percentage of tap water outages in the country.

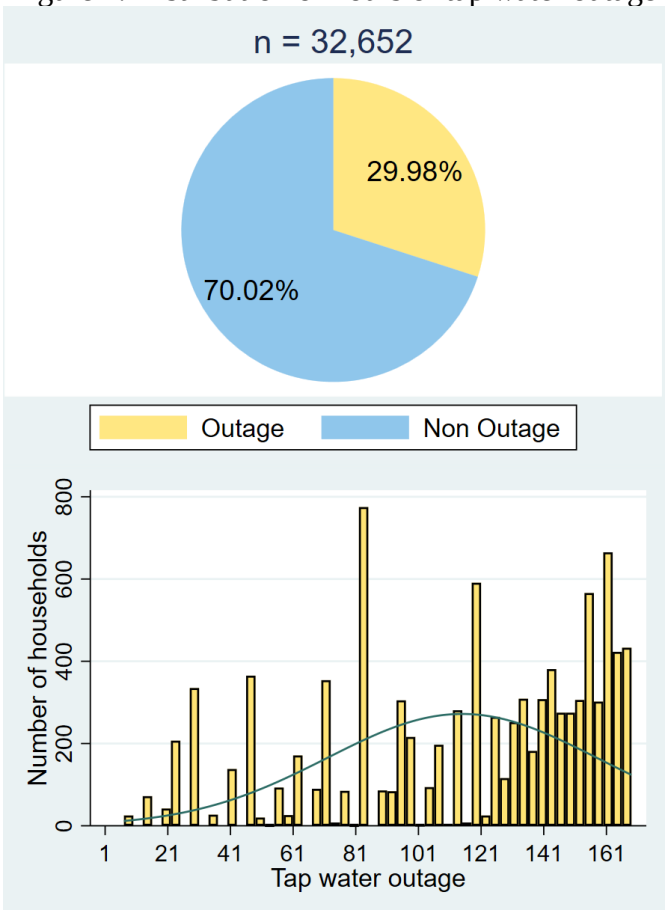
Table 1. Descriptive statistics

Variables	*N*	*Mean*	*SD.*	*Min*	*Max*
Households					
Real total household income	32652	834.24	979.66	0	9977.87
Hours of water outage	32652	34.46	57.71	0	167
Undergraduate education	32652	0.14	0.35	0	1
Household size	32652	3.49	2.11	1	28
Householder's age	32652	53.19	15.95	15	104
Female householder	32652	0.33	0.47	0	1
Water provision system					
Piped IDAAN	32652	0.7	0.46	0	1
Piped community	32652	0.29	0.45	0	1
Piped private	32652	0.02	0.13	0	1
Access to garbage collection	32652	0.71	0.46	0	1
Lives in an urban area	32652	0.6	0.49	0	1
Economically active individuals					
Hours of water outage	44178	34.43	57.87	0	167
Real total household income	44178	1176.45	1082.57	0	9977.87
Unemployed	44178	0.06	0.24	0	1
Weekly hours of work	41437	38.21	14.73	1	98
Undergraduate education	44178	0.19	0.39	0	1
Female	44178	0.42	0.49	0	1
No. of underage members in the household	44178	1.49	1.7	0	19
Age	44178	37	11.01	18	56
Household size	44178	4.5	2.47	1	28
Water provision system					
Piped IDAAN	44178	0.72	0.45	0	1
Piped community	44178	0.26	0.44	0	1
Piped private	44178	0.01	0.12	0	1
Access to garbage collection	44178	0.73	0.44	0	1
Lives in an urban area	44178	0.63	0.48	0	1

Note: Real total household income is in USD, 2010 = 100. Economically active individuals do not include those who reported not working because they are retirees, housewives, students, renters, or declared not to be looking for a job.

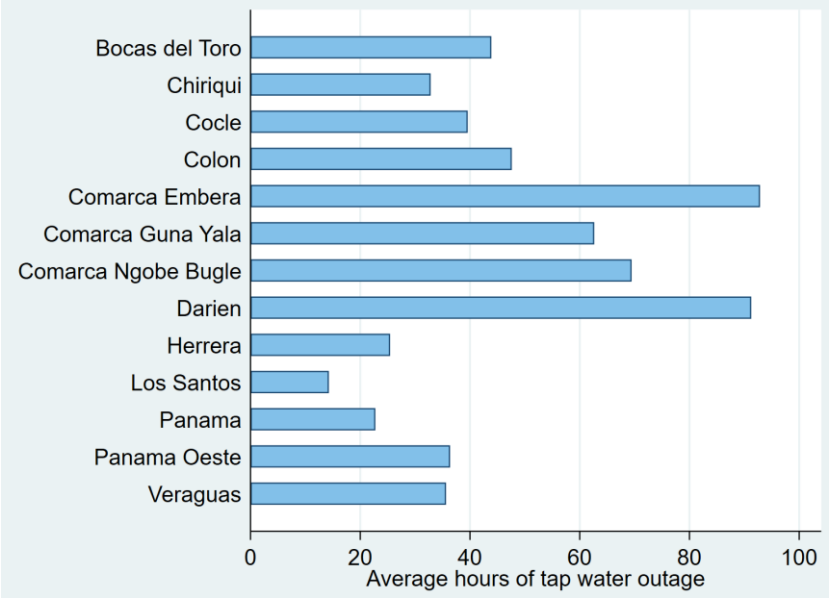
Figure 2 shows that about 30% of households reported having at least one hour of tap water outage in the week; furthermore, 24% reported having over 80 hours of outage. Differences between the average hours of outage in each province reveal that Comarcas and the province of Darien have the highest tap water provision deficiencies (Figure 3). We provide a closer look into the distribution of the hours of tap water outage by each province in Appendix Figure A1, we can observe that despite the increasing access to tap water, the percentage of households experiencing water outages is up to 66.4% in some areas.

Figure 2. Distribution of hours of tap water outage



Note: The pie chart represents the total distribution of households experiencing tap water outages in a week, while the histogram shows the frequency distribution of affected households (29.9%) with an overlaid density curve demonstrating a left-skewed distribution. Figure is constructed using data from the Multipurpose Surveys of Panama.

Figure 3. Households' average hours of tap water outage per province.



Note: The figure displays the average hours of tap water outage for households across different provinces. Each bar represents the average weekly hours of water outage experienced in a specific province, which highlights the regional disparities in water access. Figure is constructed using data from the Multipurpose Surveys of Panama.

4. Results

4.1 Baseline Estimations

Table 2 provides results on the effect of tap hours on the IHS of households' income [7]. As shown in Column 1, the negative coefficient signifies that an increase of one hour in weekly tap water outages results in a reduction of 0.07% in monthly household income. This finding aligns with existing literature on how tap water deficiencies can significantly affect the economic status of households in multiple developing countries.

When considering households that reported having water outages experienced mainly above 80 hours without weekly tap water, we can estimate these households experience around a 5.8% reduction in their monthly income. In addition, if we consider the provinces and Comarcas where households mostly experience outages above 100 hours (Figure A1), this negative impact has a larger magnitude as it can affect more than 50% of households with reported access to tap water in these areas[8]. To expand on the mechanisms causing this impact, we need to consider how access to reliable water supply affects economic activities. The infrequent water supply could increase disease prevalence, and affect general health, productivity, and job attendance. Furthermore, inadequate water access can mainly affect small-scale enterprises related to agriculture and water-based industries, reducing income generation notably in these provinces.

Adding an interaction of water outages and undergraduate education in this analysis allows us to understand the effects of acquired higher education on the response to water outages. We find how householders who completed at least 16 years of education are able to reduce the negative impact of water outages; Column 2 demonstrates that highly educated households have significantly less impact on their income than less educated households as the hours of water outage increase. One reason is that they might have better problem-solving skills and access to information, enabling them to identify and implement alternative water sources (e.g., water storage or purchasing bottled water) more effectively than households with less education. Similarly, in Appendix Table A3, we demonstrate how age can significantly help to diminish the negative impact of water outages, as older householders might develop systems and techniques over time to store water. We observe that, in comparison to younger householders (aged 15-39), the negative effect of water outages is statistically less for those aged 54-84. However, we do not observe any significant difference for householders below 54 or above 84 years. This implies that householders aged 55 to 84, might possess a suitable combination of knowledge, experience, and resources to mitigate the negative effects of water outages. This can also be explained from accumulated social capital over the years, such as better connections within the community or local governments, which allows them to request support from neighbors or receive water from water trucks.

[7] Recent literature demonstrates that the interpretation of results using IHS transformations is similar to those obtained from logarithmic forms (Barreca et al., 2021; Benček and Schneiderheinze, 2024; Fang et al., 2023). However, some caution is still necessary, as the effects might substantially deviate from the correct percentage changes (Bellemare and Wichman, 2020). Therefore, like Cui and Tang (2024), we also estimate these results using the logarithmic form of income, adding a constant to maintain the same number of observations in Table A1.

[8] Comarcas are areas with high concentrations of poverty and lacking access to public services. In Table A2, we provide results excluding these areas, discarding their possible influence on these estimators.

Table 2. Effects of weekly hours of tap water outage on monthly IHS(household income)

	(1)	(2)
Hours of water outage	-0.000730***	-0.000868***
	(0.000214)	(0.000225)
Undergraduate education	1.098***	1.083***
	(0.0352)	(0.0387)
Undergraduate education # Hours of water outage		0.00172***
		(0.000662)
Householder's age	-0.0437***	-0.0432***
	(0.000911)	(0.000912)
Female householder	-0.736***	-0.733***
	(0.0287)	(0.0287)
Household size	0.375***	0.360***
	(0.00618)	(0.00613)
Lives in an urban area	0.133***	0.140***
	(0.0380)	(0.0382)
Tap water system		
Piped community	-0.0291	-0.0288
	(0.0383)	(0.0385)
Piped private	0.141*	0.135
	(0.0843)	(0.0842)
Access to garbage collection	0.301***	0.328***
	(0.0341)	(0.0342)
N	32652	32652
F	424.4***	412.6***
Adj_R2	0.266	0.262

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls are included. The tap water systems reference group is water treatment plants.

4.2 Effect of Water Outages on Unemployment and Working Hours

Examining the implications of unemployment probability of individuals aged 18 to 56, Table 4 unveils a significant and positive coefficient of 0.0000663 for hours of tap water outages for all individuals. It can be demonstrated that this effect varies depending on gender, as women have a higher positive and significant effect on unemployment probability with each hour of outage; meanwhile, for men, we do not observe any statistically significant impact[9]. Despite the significance of the estimators in Columns 1 and 2, the estimators reflect small probabilities; in the case of women, if they experience around 80 hours of outage, the probability of unemployment would be around 1.18%. One potential mechanism explaining this effect is the time-saving aspect. Since infrequent access to tap water likely increases individuals' time collecting water or household chores burden, they are unable to allocate valuable hours to job hunting. In Panama, households without constant access to tap water often rely on water tank trucks, which require residents to wait at distribution points without prior notice of arrival, which demands considerable time and effort. Only in 2023, IDAAN reported that over 75,000 people received water from water trucks even though they had access to pipe water systems. Consequently, permanent access to tap water may alleviate the burden on individuals, enabling them to participate in the labor market more actively.

[9] In Appendix Table A4 Interactions between water outage and education levels do not show statistically significant differences. In addition, when adding controls for household income quartile levels to control for the relation between unemployment probability and different income level households, results for water outage remain significant and robust.

Table 3. Effects of weekly hours of tap water outage on unemployment probability.

	(1) All	(2) Female	(3) Male
Hours of water outage	0.0000663***	0.000148***	0.0000157
	(0.0000211)	(0.0000388)	(0.0000233)
Undergraduate education	-0.0183***	-0.0286***	-0.00599
	(0.00293)	(0.00425)	(0.00392)
Age	-0.00385***	-0.00530***	-0.00290***
	(0.000116)	(0.000210)	(0.000133)
Household size	0.00248***	0.0111***	0.000897
	(0.000543)	(0.00159)	(0.000602)
Lives in an urban area	0.00801**	0.00239	0.0118***
	(0.00364)	(0.00672)	(0.00401)
Tap water system			
Piped community	-0.0141***	-0.0185***	-0.0105***
	(0.00360)	(0.00698)	(0.00383)
Piped private	-0.0165**	-0.0172	-0.0157**
	(0.00713)	(0.0174)	(0.00672)
Access to garbage collection	0.00515	0.000224	0.00662*
	(0.00341)	(0.00653)	(0.00371)
N	44178	18761	25417
F	75.77***	43.99***	35.05***
Adj-R2	0.0489	0.0614	0.0343

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls included

Similarly, we conducted subgroup analyses to explore potential gender-based differences in the effect of water outages on working hours. In Table 4 Column 1, we show that increasing weekly hours of tap water outages is associated with a substantial decrease in weekly working hours.

The statistically significant negative impact on women contrasts with a lower negative and insignificant effect on men, as shown in Column 3. These results suggest that for female workers, 1 hour more of water outage is associated with dedicating approximately 26.86 seconds less to productive activities in a week. Since we observed that households with water outages mostly experience more than 80 hours of outage, we could determine a reduction of more than 35 minutes in productive activities in a week. Additionally, the negative estimator of underage members on working hours and the adverse relationship with the number of household members working suggest noteworthy household behaviors. Increased household responsibilities due to childcare and intra-household labor dynamics may shape individual working hours. Specifically, for women, there is a decrease in their working hours as the number of underage members increases, while for men, the opposite seems to happen, where they work more hours. These findings offer further socio-economic insights into expected roles and responsibilities within Panamanian households[10].

Column 2 also provides an understanding of the effects of women's education on mitigating the effects of hours of outage; if female workers are highly educated and experience increasing water outages, they can spend more time on productive activities than less educated women.

[10]We estimate these results by including household income quartile controls. This ensures that the observed impact on working hours is directly attributable to water outages rather than underlying household socioeconomic disparities, which can affect individuals' labor time allocation. Appendix Table A5 shows robust and similar results regarding the impact of water outages and education on working hours.

This implies that higher-educated women can also apply effective strategies to manage household disruptions and focus on income-generating work, allowing them to minimize time spent on non-productive activities like fetching water.

Succinctly, our results provide strong evidence and clarify the connections among water infrastructure, gender dynamics, and economic outcomes, contributing meaningfully to the literature on the maintenance of tap water infrastructure and its implications for gender roles.

Table 4. Effects of weekly hours of tap water outage on weekly working hours of female and male workers.

	(1) Female	(2) Female	(3) Male	(4) Male
Hours of water outage	-0.00746***	-0.0104***	0.00138	0.000813
	(0.00211)	(0.00247)	(0.00156)	(0.00164)
Undergraduate education	1.070***	0.724**	0.393	0.241
	(0.270)	(0.281)	(0.287)	(0.297)
Undergraduate education # Hours of water outage		0.0150***		0.00740*
		(0.00374)		(0.00442)
Age	-0.00906	-0.00875	0.0612***	0.0612***
	(0.0107)	(0.0107)	(0.00807)	(0.00807)
No. of underage members in the household	-0.593***	-0.590***	0.452***	0.453***
	(0.122)	(0.122)	(0.0951)	(0.0951)
Household size	0.106	0.106	-0.140**	-0.140**
	(0.0832)	(0.0831)	(0.0625)	(0.0625)
Lives in an urban area	2.286***	2.303***	0.222	0.230
	(0.367)	(0.367)	(0.273)	(0.273)
Tap water system				
Piped community	-1.199***	-1.190***	-1.308***	-1.309***
	(0.400)	(0.399)	(0.289)	(0.289)
Piped private	0.652	0.663	-0.777	-0.782
	(1.082)	(1.083)	(0.701)	(0.701)
Access to garbage collection	2.370***	2.352***	1.015***	1.010***
	(0.377)	(0.376)	(0.252)	(0.252)
N	17215	17215	24222	24222
F	245.1***	237.4***	100.7***	97.60***
Adj-R2	0.237	0.238	0.118	0.118

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province, year controls, and occupation categories are included.

5. Conclusion and Policy Implications

This study demonstrates that inconsistent tap water access, measured by weekly hours of tap water outage can significantly reduce monthly household income, increase unemployment probabilities, and reduce the hours female workers dedicate to productive activities in Panama. We argue that increasing the number of households receiving tap water should be accompanied by a plan for providing consistent and adequate maintenance of tap water infrastructure. Once these limitations are diminished, we might observe higher household incomes, lower unemployment probabilities, and increasing labor market participation especially decreasing the barriers for women to contribute to the overall economic development of their areas.

These findings allow us to provide some relevant policy implications, first, local governments should prioritize the creation of long-term resilient water infrastructure for improving individuals' well-being, while applying strategies to repair already damaged pipes and upgrade outdated systems to ensure a consistent water supply, especially in economically disadvantaged areas. Moreover, increasing the number of water meters could facilitate the reduction of non-revenue water losses and water leaks might be easier to find; however, more research needs to be done on this matter.

Second, rural aqueducts serve more than 30% of households in Panama, and they present significant challenges in the long-term storage of water. Hence, the organizations in charge might need to empower community-based water management groups with more resources and training to improve the maintenance and preservation of local water systems. Given the increasing threat of droughts, an updated community-led approach could ensure sustainable water management practices and residents' active participation.

Third, high precipitation in Panama might make residents take tap water provision for granted without acknowledging all the investment and costs associated with preserving water sources, treating, and transporting potable water to each location. This often results in numerous late water service payments. Therefore, implementing education programs and marketing campaigns can help communities understand their role in maintaining water infrastructure and reduce non-revenue water losses.

Finally, once a plan to address tap water deficiencies is implemented, the entities in charge should establish robust monitoring and evaluation frameworks to assess its effectiveness. This continuous assessment will help identify gaps and areas for improvement to ensure that investments translate into tangible socio-economic benefits.

By considering these policy implications, Panama can make significant strides in improving clean tap water access, which will undoubtedly result in economic growth, a better quality of life, and equitable development across the country.

One limitation of our study is the lack of detailed household location information, which could help to precisely identify the most affected areas by inconsistent water provision and inform more targeted policy recommendations. Despite this, our study makes a compelling case for prioritizing water infrastructure and management in national development strategies.

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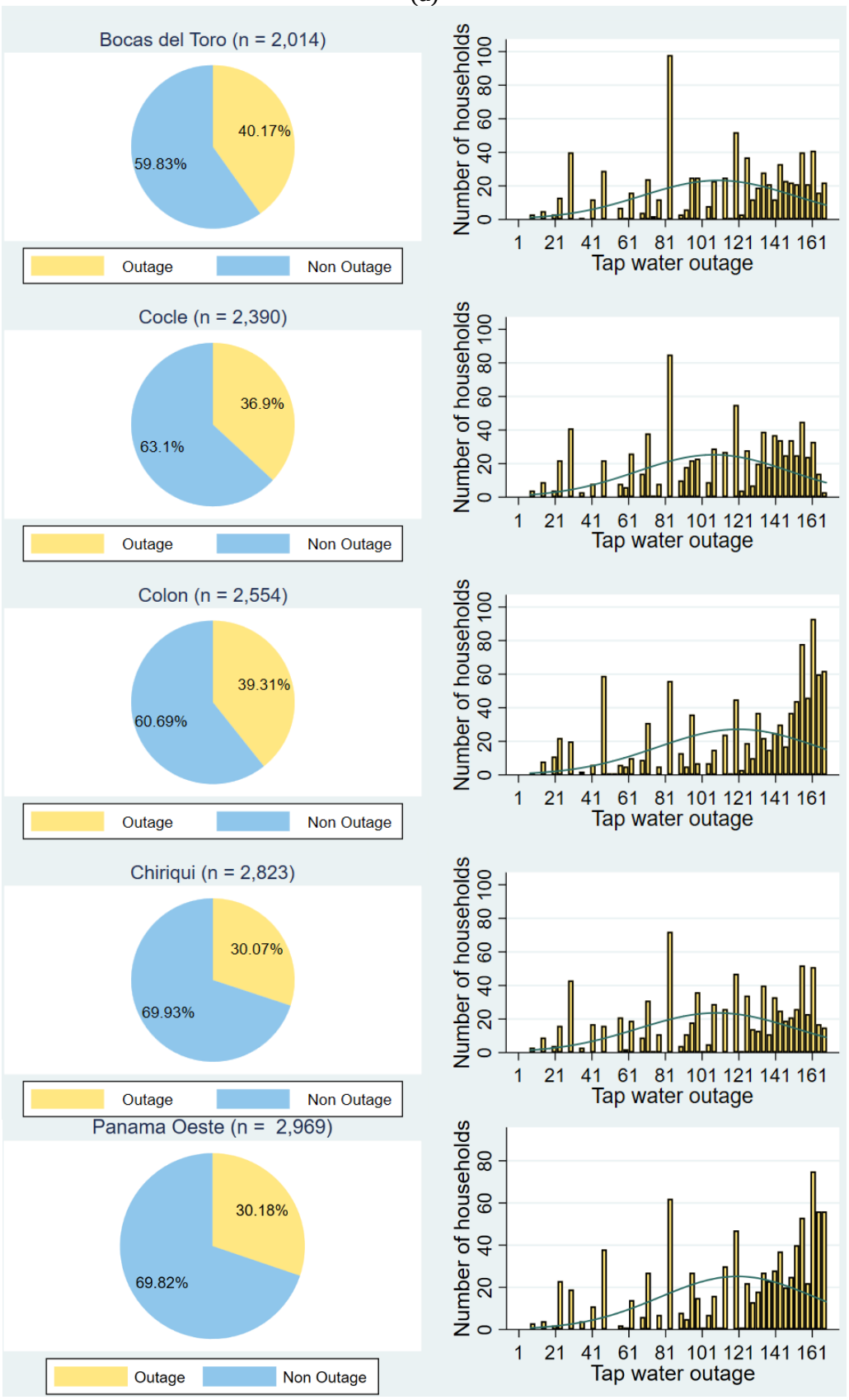
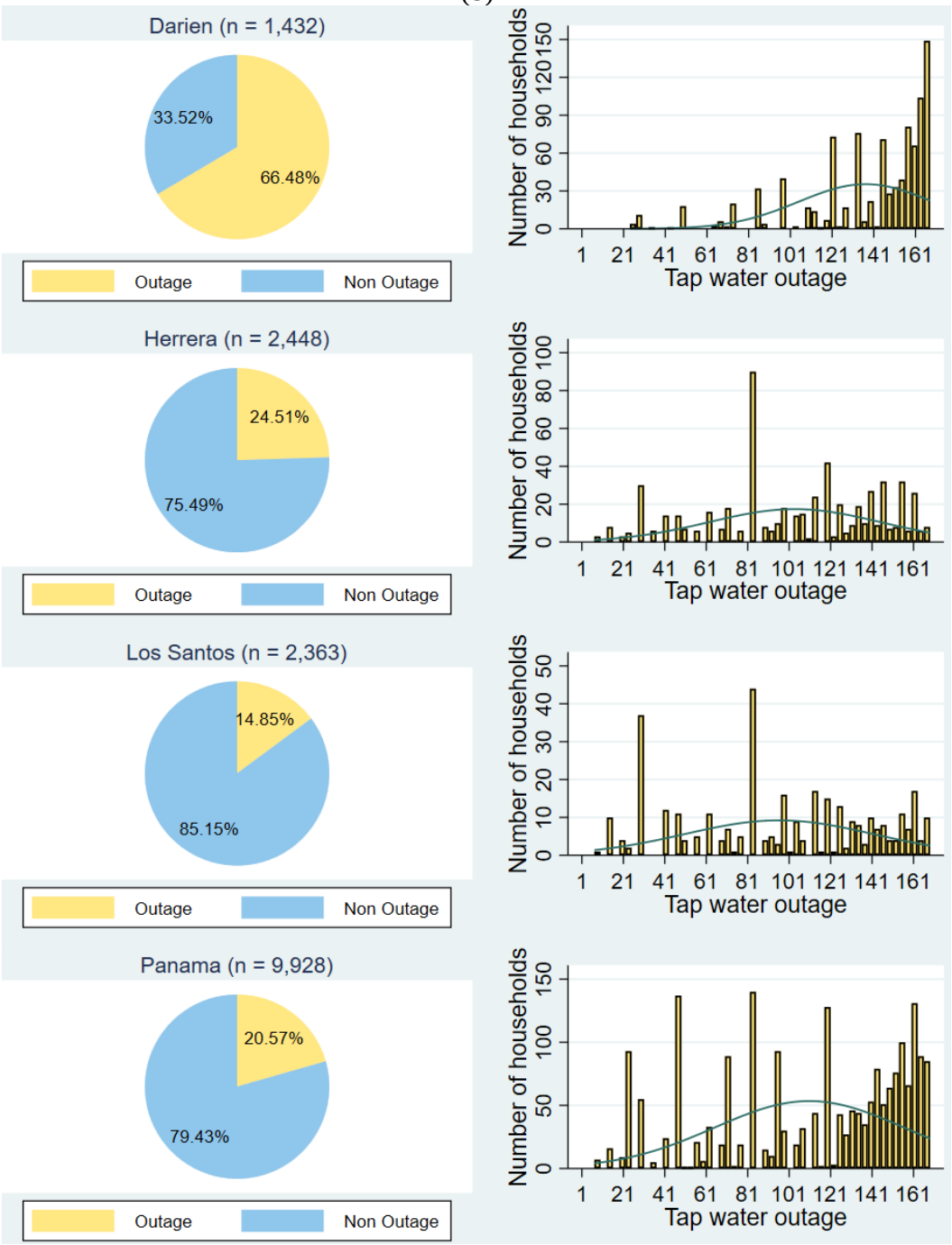
Appendix

Figure A1. Distribution of hours of tap water outage per provinces and Comarcas

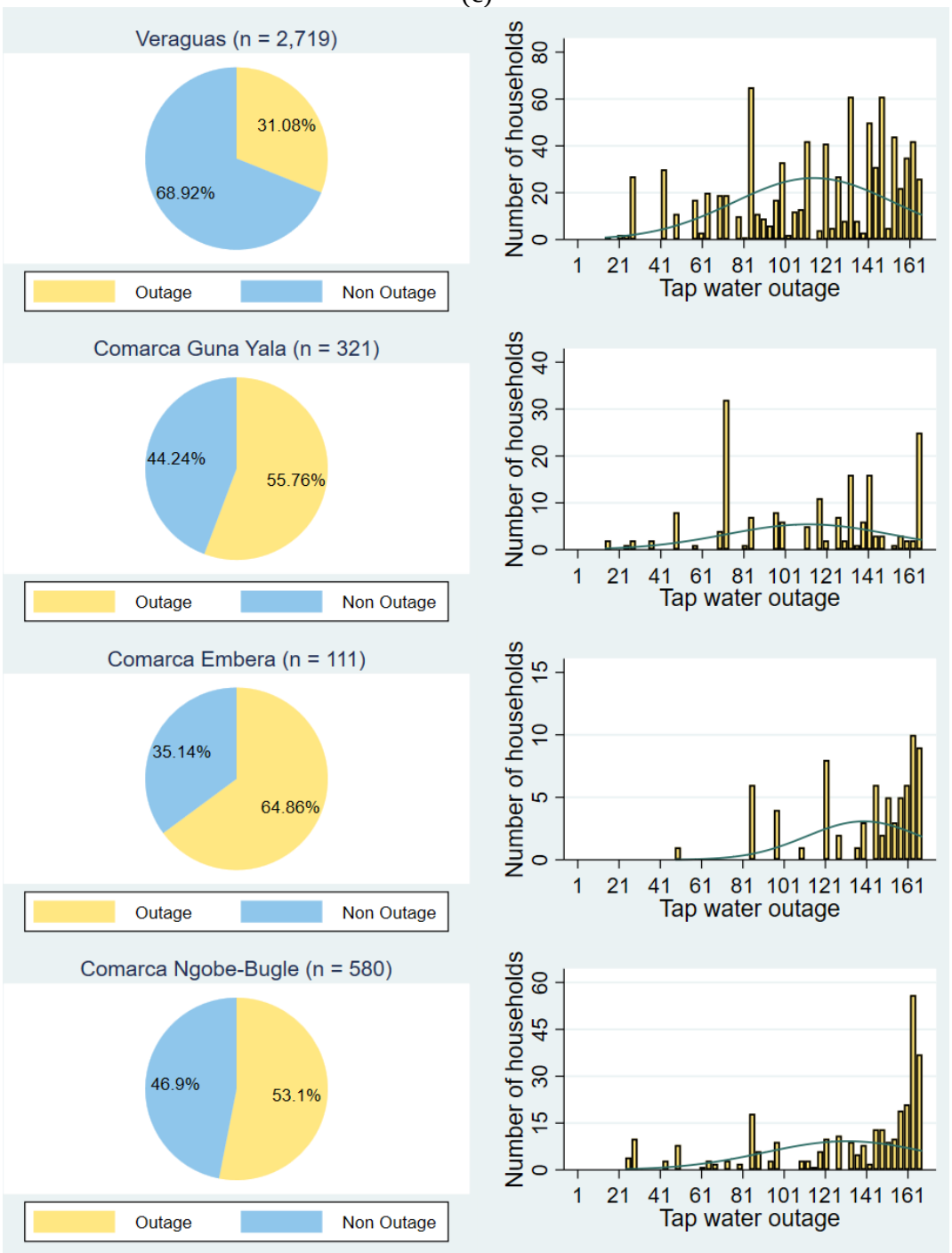
(a)



(b)


Darien (n = 1,432)
33.52%
66.48%
Outage
Non Outage
Herrera (n = 2,448)
24.51%
75.49%
Outage
Non Outage
Los Santos (n = 2,363)
14.85%
85.15%
Outage
Non Outage
Panama (n = 9,928)
20.57%
79.43%
Outage
Non Outage
Number of households
0 30 60 90 120150
1 21 41 61 81 101 121 141 161
Tap water outage
Number of households
0 20 40 60 80 100
1 21 41 61 81 101 121 141 161
Tap water outage
Number of households
0 10 20 30 40 50
1 21 41 61 81 101 121 141 161
Tap water outage
Number of households
0 50 100 150
1 21 41 61 81 101 121 141 161
Tap water outage

(c)



Note: The left panel displays the number of households and the percentage that experience at least one hour of outage by province and comarca. The right panel shows the number of households corresponding to the different hours of tap water outage in a week with an overlaid density curve demonstrating a left-skewed distribution. Figure is constructed using data from the Multipurpose Surveys of Panama.

Table A1. Effects of weekly hours of tap water outage on monthly log(household income)

	(1) Log(Inc+1)	(2) Log(Inc)	(3) Log(Inc)
Hours of water outage	-0.000676***	-0.000347***	-0.000376***
	(0.000196)	(0.000103)	(0.000109)
Undergraduate education	1.083***	0.867***	0.860***
	(0.0325)	(0.0141)	(0.0152)
Undergraduate education # Hours of water outage			0.000313
			(0.000293)
Householder's age	-0.0394***	-0.00693***	-0.00693***
	(0.000829)	(0.000394)	(0.000394)
Female householder	-0.678***	-0.250***	-0.251***
	(0.0262)	(0.0124)	(0.0124)
Household size	0.336***	0.141***	0.141***
	(0.00564)	(0.00283)	(0.00283)
Lives in an urban area	0.138***	0.172***	0.172***
	(0.0348)	(0.0174)	(0.0174)
Tap water system			
Piped community	-0.0463	-0.214***	-0.214***
	(0.0351)	(0.0185)	(0.0185)
Piped private	0.104	-0.148***	-0.148***
	(0.0773)	(0.0457)	(0.0457)
Access to garbage collection	0.332***	0.421***	0.420***
	(0.0312)	(0.0165)	(0.0165)
N	32652	28821	28821
F	462.8***	582.7***	559.0***
Adj-R2	0.270	0.333	0.333

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls are included. Columns 2 and 3 use the log of household income without adding a constant which excludes households with 0 income.

Table A2. Effects of weekly hours of tap water outage on monthly IHS(household income) excluding Indigenous areas

	(1)	(2)	(3)
Hours of water outage	-0.000888***	-0.00103***	-0.00361***
	(0.000222)	(0.000232)	(0.000779)
Undergraduate education	1.103***	1.070***	1.101***
	(0.0356)	(0.0389)	(0.0356)
Householder's age	-0.0440***	-0.0440***	-0.0457***
	(0.000926)	(0.000926)	(0.00108)
Undergraduate education # Hours of water outage		0.00166**	
		(0.000684)	
Hours of water outage # Householder's age			0.0000517***
			(0.0000156)
Female householder	-0.725***	-0.726***	-0.724***
	(0.0294)	(0.0294)	(0.0294)
Household size	0.377***	0.377***	0.377***
	(0.00631)	(0.00632)	(0.00632)
Lives in an urban area	0.139***	0.140***	0.137***
	(0.0382)	(0.0382)	(0.0382)
Tap water system			
Piped community	-0.0279	-0.0264	-0.0298
	(0.0387)	(0.0387)	(0.0387)
Piped private	0.158*	0.159*	0.159*
	(0.0867)	(0.0867)	(0.0866)
Access to garbage collection	0.331***	0.329***	0.330***
	(0.0343)	(0.0343)	(0.0343)
N	31640	31640	31640
F	484.0***	461.0***	461.4***
Adj-R2	0.266	0.266	0.266

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls are included.

Table A3. Effects of weekly hours of tap water outage on monthly IHS(household income) interactions with age group

	IHS(household income)
Hours of water outage	-0.00129***
	(0.000361)
Age 40-54 # Hours of water outage	0.0000156
	(0.000435)
Age 55-84 # Hours of water outage	0.00143***
	(0.000519)
Age 85-104 # Hours of water outage	0.00275
	(0.00225)
Undergraduate education	1.125***
	(0.0355)
Female householder	-0.752***
	(0.0286)
Household size	0.353***
	(0.00619)
Lives in an urban area	0.134***
	(0.0384)
Tap_water_system	
Piped community	-0.0569
	(0.0386)
Piped private	0.118
	(0.0841)
Access to garbage collection	0.328***
	(0.0343)
N	32524
F	355.1***
Adj-R2	0.253

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls are included.

Table A4. Effects of weekly hours of tap water outage on unemployment probability (including income quartiles)

	(1) All	(2) All	(3) Female	(4) Male
Hours of water outage	0.0000578***	0.0000486**	0.000109***	0.00000870
	(0.0000224)	(0.0000209)	(0.0000380)	(0.0000232)
Undergraduate education	-0.0198***	0.0138***	0.0230***	0.0206***
	(0.00315)	(0.00318)	(0.00470)	(0.00421)
Undergraduate education # Hours of water outage	0.0000687			
	(0.0000584)			
Age	-0.00385***	-0.00384***	-0.00524***	-0.00266***
	(0.000116)	(0.000114)	(0.000204)	(0.000128)
Household size	0.00249***	0.00734***	0.0306***	0.0194***
	(0.000543)	(0.000564)	(0.00174)	(0.00116)
Lives in an urban area	0.00807**	0.0164***	0.0112*	0.0177***
	(0.00364)	(0.00360)	(0.00657)	(0.00398)
Tap water system				
Piped community	-0.0140***	-0.0223***	-0.0287***	-0.0198***
	(0.00360)	(0.00361)	(0.00688)	(0.00386)
Piped private	-0.0165**	-0.0267***	-0.0304*	-0.0225***
	(0.00714)	(0.00728)	(0.0180)	(0.00688)
Access to garbage collection	0.00507	0.0201***	0.0196***	0.0185***
	(0.00341)	(0.00343)	(0.00646)	(0.00373)
Quartile 2		-0.0618***	-0.0860***	-0.0581***
		(0.00375)	(0.00665)	(0.00439)
Quartile 3		-0.0944***	-0.143***	-0.0848***
		(0.00393)	(0.00690)	(0.00479)
Quartile 4		-0.124***	-0.198***	-0.114***
		(0.00425)	(0.00761)	(0.00544)
N	44178	44178	18761	25417
F	72.65***	83.71***	53.92***	37.39***
Adj-R2	0.0489	0.0756	0.107	0.0650

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province and year controls are included. "Quartile 1" or people with the lowest income is the reference category.

Table A5. Effects of weekly hours of tap water outage on weekly working hours of female and male workers (including income quartiles)

	(1) Female	(2) Female	(3) Male	(4) Male
Hours of water outage	-0.00673***	-0.00950***	0.00153	0.00117
	(0.00208)	(0.00243)	(0.00154)	(0.00162)
Undergraduate education	0.355	0.0285	-0.335	-0.434
	(0.274)	(0.285)	(0.286)	(0.296)
Undergraduate education # Hours of water outage		0.0141***		0.00475
		(0.00370)		(0.00441)
Age	-0.00363	-0.00336	0.0655***	0.0654***
	(0.0105)	(0.0105)	(0.00794)	(0.00794)
No. of underage members in the household	0.120	0.123	1.093***	1.094***
	(0.126)	(0.126)	(0.101)	(0.101)
Household size	-0.595***	-0.595***	-0.778***	-0.778***
	(0.0906)	(0.0906)	(0.0697)	(0.0697)
Lives in an urban area	2.087***	2.103***	-0.148	-0.142
	(0.363)	(0.363)	(0.270)	(0.270)
Tap water system				
Piped community	-0.851**	-0.844**	-0.855***	-0.855***
	(0.393)	(0.393)	(0.285)	(0.285)
Piped private	1.164	1.173	-0.414	-0.417
	(1.046)	(1.047)	(0.686)	(0.686)
Access to garbage collection	1.834***	1.818***	0.354	0.351
	(0.371)	(0.370)	(0.248)	(0.248)
Quartile 2	3.827***	3.814***	5.135***	5.132***
	(0.357)	(0.357)	(0.270)	(0.270)
Quartile 3	6.491***	6.472***	6.689***	6.680***
	(0.370)	(0.370)	(0.287)	(0.287)
Quartile 4	6.992***	6.996***	7.379***	7.381***
	(0.412)	(0.412)	(0.327)	(0.327)
N	17215	17215	24222	24222
F	237.6***	230.9***	111.4***	108.2***
Adj-R2	0.256	0.256	0.145	0.145

Note: Robust standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Province, year controls, and occupation categories are included. . "Quartile 1" or people with the lowest income is the reference category.