Review on Urban Water & Sanitation on three topics: Subsidy Incidence, Price Elasticities, and Relations to Health.

Framework and Research Paths for Future Studies

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Infrastructure and Energy Sector

TECHNICAL NOTE Nº IDB-TN-2407

January 2022

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This technical note is product of a consultancy funded by the operation "Impact of access to water on COVID-19 morbidity and mortality: a study in peri-urban areas of Lima, Peru" (RG-E1786).

January 2022

Inter-American Development Bank

Cataloging-in-Publication data provided by the
Inter-American Development Bank
Felipe Herrera Library
Cárdenas, Helena C.
Review on urban water & sanitation on three topics: subsidy incidence, price elasticities, and relations to health: framework and research paths for future studies / Helena C. Cárdenas.
p. cm. — (IDB Technical Note ; 2407)
Includes bibliographical references.
1. Water-security-Research-Latin America. 2. Water-security-Research-Caribbean Area. 3. Sanitation-Research-Latin America. 4. Sanitation-Research-Caribbean Area. 5. Coronavirus infections-Latin America. 6. Coronavirus infections-Caribbean Area. I. Inter-American Development Bank. Infrastructure and Energy Sector. II. Title. III. Series.
IDB-TN-2407

JEL Code: H2, L95, I15

Keywords: water, sanitation, pricing, elasticity, subsidies, health.

http://www.iadb.org

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December 2021[2] [3]

Introduction

Cities around the world are struggling to count on effective water management strategies. Some of the frequent difficulties are related to water resources availability, high production and distribution costs (with very capital-intensive investments), water losses from utility companies' operations and other maintenance problems that impact service quality, water wastage from consumers, insufficient service coverage rates and therefore parts of population without access to safe water and sanitation. These challenges are becoming even greater with population growth, urban expansion, increasing inequalities, climate change, and looming public health emergencies, like pandemics.

The United Nations has insistently warned in the last decades that *'providing safe and affordable drinking water and sanitation to the residents of rapidly growing urban areas in developing countries has constituted one of the greatest challenges of sustainable development'*[4]. This unmet goal is a matter of concern to policymakers, utility companies, and the general population. Water utility companies' puzzle is to define mechanisms that better help them to recover the costs of their investments and develop financial sustainability, while promoting water conservation and developing management programs that allow them to watch over the quantity and quality of the services. Policymakers and regulators look out for various objectives, including: environmental conservation and sustainable use of water resources, global access to the required services, particularly looking at reaching poor populations, and remedy of deficiencies (e.g. coverage, reliability, continuity, quality) in the provision of these services because of their links to public health and diseases control.

This document presents a review of the literature on three pressing policy issues that currently are of relevance to regulators and utility companies in the water and sanitation sector:

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[4] UN (2007). *Providing water to the urban poor in developing countries: the role of tariffs and subsidies*, October 2007 Sustainable Development Innovation Briefs; UN (2014). *The Millennium Development Goals Report*, 2014, UN, New York, 2014; UN (2020). *The Millennium Development Goals Report, 2020*, UN, New York, 2020; UNESCO, UN-Water (2020). *The United Nations World Water Development Report*, 2020. Water and Climate Change, Paris, UNESCO.

i) ***Subsidy incidence:*** this review covers key studies that evaluate how subsidies have been distributed among income groups in the water and sanitation sector. First, it provides an overview on the types of subsidies that have been used in this sector, their objectives, their results, and what concerns have been presented in the literature in the last decades. This review looks at how studies in the literature have evaluated subsidy incidence and leakage, what conclusions have they reached, and what new questions are being asked to improve persistent challenges in subsidy incidence in this sector. The question on how successful is the distribution of subsidies among income groups is of high relevance, because it is fully related to outcomes on poverty alleviation, service coverage, as well as financial sustainability of the water service provider.

ii) ***Responses to pricing policies:*** this review covers studies on price elasticities of residential piped water demand in urban areas. First, it summarizes meta-analyses implemented on this topic and their results about factors that might impact the empirical estimation of these price elasticities. Then, this review focuses on studies that evaluate a single location and which have been able to use micro-data. For these studies, it summarizes the types of data and variables used in modeling, estimation techniques that have been used, results and conclusions reached, and areas where further research is needed. The question on how households in urban areas respond to pricing policies is indispensable for regulators and utility companies to address. City-specific analyses on this question will be key to improve water resource efficient use (through demand-side management), as well as to evaluate how customers' payments can help services cost recovery and through which strategies.

iii) ***Relations to health:*** this review provides and synopsis of the relation between water security and human health impacts, including impacts of COVID-19. First, it provides a general framework on the relation of water security and health, based on systematic reviews and meta-analyses. Next, it reviews studies on the relation between housing conditions, as well as socio-economic determinants, and COVID-19 health impacts. Later, it focuses more precisely on quantitative studies that evaluate relations between access to piped water and sanitation and COVID-19 incidence, mortality, and fatality rates. Finally, it summarizes studies that have analyzed causality between access to piped water and sanitation and other health impacts. The purpose of the last section of the analysis is to exemplify the type of data and methodologies that have been used in those studies that isolate the impact of piped water access on health variables. The question on the relation between water security and health is central to develop strategies to face public health hazards. Researchers and policymakers should carefully evaluate these links, by appropriately taking into consideration possible behavioral confounders and socio-economic characteristics.

The objective of presenting an overview of the literature on these three topics is to delineate the findings, methods, and persistent questions, in order to provide a framework for future studies. As more cities in Latin America and other regions look for ways to tackle challenges in the water and sanitation sector, these reviews can help them to evaluate and plan their case studies. This document does not intend to be exhaustive in terms of the number of studies included, but its main purpose is to thoroughly highlight issues and questions that will benefit from new local empirical analyses, to improve the design of policies in the water and sanitation sector.

1. Subsidy Incidence for Water and Sanitation Sector

Subsidies incidence for the infrastructure sector, including water, electricity, and public transport, has been a matter of study for various decades. Two key questions throughout these years have been: First, whether infrastructure subsidies are helping to reduce poverty and improving human population access to basic services. The second is whether pricing policies are simultaneously achieving resource management and financial sustainability for service providers. Most of the literature to this date shows that much improvement is still needed.

With the goal of poverty alleviation, some priorities have been identified in the infrastructure sector, mainly: facilitating access of the poor population to safe water and sanitation, energy resources, and transportation, and ensuring consumption affordability of these services (Estache, Foster and Wodon, 2002; Banerjee and Morella, 2011; Angel-Urdinola and Wodon, 2012). Subsidies and pricing policies, including tariff design for utility services of water and electricity, have long been evaluated along these priorities; however, there has been much controversy about how to prioritize the objectives of tariff design, among them: revenue cost recovery, economic efficiency, and social objectives (Whittington, 1992; Boland and Whittington, 2000; Foster and Yepes, 2006; Komives, Halpern, Foster, Wodon, *et al.*, 2007; Bacon *et al.*, 2010; Banerjee *et al.*, 2010; Whittington, 2011).

Energy and water subsidies are large and widespread in developed and developing countries (Bacon *et al.*, 2010; Andrés *et al.*, 2020). Subsidy programs, in particular for water and electricity sectors, have been delivered through direct and indirect targeting. Direct targeting identifies beneficiary households by qualifying characteristics, such as low income or location in an impoverished locality. Cases of direct targeting are much less in number because of the logistic and financial demands of these programs. Indirect targeting delivers subsidies through the tariff structure, by selling some services below total average cost. This approach has been called "quantity-based mechanism". Like it will be evident in this literature review, quantity-based mechanisms are the most common instrument to subsidize water and electricity services in the developing world. Policy makers have perceived this type of in-kind transfers as an attractive mechanism for income redistribution because of its lower administrative costs in comparison to direct targeting (Komives, Halpern, Foster, Wodon, *et al.*, 2007)[5].

Nevertheless, concerns about the performance of quantity-based mechanisms as an instrument for poverty alleviation have prompted empirical evaluations. Several studies have analyzed the targeting performance of these mechanisms, and to this date the literature has widely reported the unsuccessful targeting of subsidies in the infrastructure sector, including water and electricity (Coady, Grosh and Hoddinott, 2004; Foster and Araujo, 2004; Komives *et al.*, 2005, 2006; Komives, Halpern, Foster, Wodon, *et al.*, 2007; Angel-Urdinola and Wodon, 2007; Bacon *et al.*, 2010; Angel-Urdinola and Wodon, 2012; Cardenas and Whittington, 2019; Abramovsky *et al.*, 2020). The issues of quantity-based mechanisms should be understood by evaluating the tariff structure design. Intents of incorporating social objectives of affordability, equity, and poverty alleviation initially motivated tariff designs, such as IBTs (increasing block tariffs) or VDTs

[5] For long time, quantity-based mechanisms have been thought as attractive transfer mechanisms because they are usually administered by a single network service provider, periodic billing provides a simple way of handling the subsidy, and both of these characteristics have provided a way to deliver subsidies to the poor with lower administrative costs (Komives *et al.*, 2006; Komives, Halpern, Foster, Wodon, *et al.*, 2007).

(volume-differentiated tariffs), to subsidize certain levels of water consumption by self-selection. However, self-selection based on consumption has shown limited potential for good targeting.

The most important reason for the failure of IBTs and VDTs to reach the poor is based on unrealistic assumptions about the quantity of services that a poor household needs or uses, as compared to a wealthier household. The relationship of water or electricity consumption and income has not proved to be straightforward, especially in developing countries. Several reasons have been cited for the failure of quantity-based mechanisms as instrument for poverty alleviation, including: 1) poor families are often significantly larger than wealthier ones, 2) some poor families in many cases share connections with a joint meter; 3) quantity based mechanisms also subsidize non-poor water users, and the level of such subsidy can be quite high if the first block is beyond subsistence consumption; and 4) poor households are sometimes renters and if the primary account holder receives a quantity based subsidy, it is unlikely that it would be passed through to poor renters who share the connection (Whittington, 1992; Boland and Whittington, 2000; Foster and Yepes, 2006; Dahan and Nisan, 2007; Barde and Lehmann, 2014; Cardenas and Whittington, 2021).

Moreover, not only quantity-based mechanisms have underperformed as instruments for poverty alleviation, but they have also worsened the goal of cost recovery for service providers, as they have proved to be expensive and poorly targeted (Boland and Whittington, 2000; Estache, Foster and Wodon, 2002; Bacon *et al.*, 2010; Andres *et al.*, 2019). Analyses on the magnitude of resources that are being allocated to utility subsidies show that these amounts are quite sizeable. For example,
Andrés *et al.* (2020) estimate that total subsidies for networked water and sewerage services are at around 0.5% of GDP worldwide, and over 1.5% of GDP for non-advanced economies. Cardenas and Whittington (2019) also summarize the magnitude of electricity subsidies in the literature. Both of these studies show that the magnitude of utility subsidies for residential consumers in developing countries represent a large burden on the public budget.

Subsidies for water and electricity through direct targeting have also been studied in the literature, even if there have only been a handful of these studies. In contrast to what the literature has found on quantity-based mechanisms, studies that have analyzed interventions of means testing and geographic targeting have shown progressive results (Gómez-Lobo and Contreras, 2003; Coady, Grosh and Hoddinott, 2004; Foster and Yepes, 2006; Melendez, 2008). Yet, when compared to other targeted subsidies, utility subsidies typically are less well targeted than these other social transfer programs (Wodon and Yitzhaki, 2002). Further evidence on direct targeting for utility subsidies is still necessary. New studies will help to further improve the understanding of this type of subsidy targeting, its challenges, and their magnitude. Comparison of the performance of direct subsidies to quantity-based subsidies should also help to move the path forward for improving subsidy targeting in the infrastructure sector to reach the poor.

In the rest of this literature review, I describe the methods for subsidy estimation and type of data used in subsidy incidence analyses, later I describe the subsidy incidence analyses for the water and sanitation sector with indirect and direct targeting, and lastly, I conclude.

1.1 Methods for subsidy estimation and type of data used in subsidy incidence analyses

Concepts and definitions

The methods used for subsidy incidence analysis are standard in the literature and their selection mostly depend on data availability. There are three main metrics to evaluate subsidy incidence: beneficiary incidence, benefit incidence, and materiality or magnitude of the subsidy. *Beneficiary incidence* provides a measure of poor households' access to public services. It addresses the question: 'of the total number of poor households, what proportion receive the subsidy?' Results are typically presented as the share of targeted households that received the subsidy, or as the share of poor households excluded from receiving the subsidy ("errors of exclusion"). *Benefit incidence* describes the distribution of the total subsidy across different income or wealth groups in the total population. It analyses the question: 'How well does the subsidy benefit poor households, as compared to other households?' In a benefit incidence analysis, the distribution or incidence of subsidies would be defined as "regressive" if rich households received a high proportion of the total subsidies delivered to all households. Common metrics used in benefit incidence analysis include: subsidy distribution among any type of quantiles (e.g. quartiles, quintiles, deciles), leakage rate, benefit targeting performance indicator (which has been called in various papers as the omega estimator (Ω)), errors of inclusion, concentration coefficients, and some authors use a quasi-Gini coefficient. Finally, *Magnitude or Materiality of the Subsidy* responds to the question: 'what is the scale or size of subsidy received by poor households, or by the population as a whole?" The answer is generally reported as the total amount of the subsidy as a proportion of the total financial cost of service provision, or as a proportion of a national macroeconomic measure, such as GDP or the fiscal deficit.

In general, the definition of 'poor households' is based either on a percentile defined by the authors, or on a government poverty line to distinguish between poor and non-poor households. If authors define a percentile, the poor population is defined at either the poorest quintile of the population income (or wealth) distribution, the three first deciles, or the poorest two quintiles.

Methods and Data for Cost Estimation

Various studies in the literature use estimates for the average unit cost of service provision based on data from national or international benchmarks (Pattanayak and Yang, 2002; Prokopy, 2002; Foster, 2004; Foster and Araujo, 2004; Komives *et al.*, 2005; Foster and Yepes, 2006; Melendez, 2008). Other studies use site-specific cost estimates, such as references from utility companies (Walker *et al.*, 2000; Groom *et al.*, 2008; Banerjee and Morella, 2011; Fuente *et al.*, 2016; Cardenas and Whittington, 2021). In some cases, national or international benchmarks may be the only sources of costs of water provision and maybe the only way to approximate costs of potable water production and distribution. Nevertheless, the most reliable sources would be cost data obtained from the utility service provider at the studied location. These sources might be able to indicate further information to account for operating and capital costs (Fuente *et al.*, 2016; Cardenas and Whittington, 2021). The inclusion of capital costs in the cost estimation and cost recovery analysis is of particular importance in the water and sanitation sector. Water and sanitation investments are very capital intensive; therefore, these costs are generally incurred early in the life of the project, and the benefits of the project are then streamed over many years (Whittington, 2011).

The analysis of implicit subsidies for public utilities is currently moving towards a more comprehensive analysis of the cost of public services (Ebinger, 2006; Ebeke *et al.*, 2015; Kochhar *et al.*, 2015). Particularly, in the water sector and electricity sectors, national regulators and academics are moving towards the use of the concept of '*cost-reflective tariffs*'. Cost-reflective tariffs reveal a comprehensive cost of supplying the service, including capital and recurrent costs of providing service, and remove the reliance on government subsidies. For example, Andrés *et al.* (2020) estimate water supply and sanitation subsidies for a global database using cost-reflective tariff approach. They used utility-level data from the World Bank's Water and Sanitation Utilities database of the International Benchmarking Network (IBNET) and complemented these utility-specific data with estimates of the long-term incremental costs of an efficient firm model, taking estimates from Chile as a benchmark.[6] The subsidies for each firm of the global database were then computed as the difference between this cost-reflective full tariff and the effective tariff that a utility company collects. When cost reflective tariffs are taken into consideration in the analysis, estimated subsidies are larger and they show a more realistic picture of the public budget allocated to utility subsidies. Abramovsky *et al.* (2020) in their multi-country study, found that all countries had a higher cost-reflective tariff than the average unit price paid by all households that report paying a positive amount for piped water, and that six out of the ten evaluated countries had a unit price higher than the estimated operating cost of the cost-reflective tariff.

Socio-Economic & Consumption Data

Most studies in this literature use secondary socio-economic data to obtain information on income and wealth, as well as to back calculate levels of water use. These are generally publicly funded household surveys on income and expenditures, which cover a range of dimensions of households' characteristics, including income and spending patterns (Walker *et al.*, 2000; Pattanayak and Yang, 2002; Prokopy, 2002; Foster and Yepes, 2006; Komives *et al.*, 2006; Angel-Urdinola and Wodon, 2007; Groom *et al.*, 2008; Barde and Lehmann, 2014; Abramovsky *et al.*, 2020). Other studies use secondary sources from household surveys targeted to the understanding of service provision, or used for the subsidy implementation program itself. Gómez-Lobo and Contreras (2003), who analyzed the cases of Chile and Colombia, used data from a survey that identified subsidy beneficiaries for the case of Chile, and data from the utility companies on subsidies by the classification of dwellings for the case on Colombia. (Foster, 2004) used data from a household survey representative of urban areas that collected expenditure data and consumption patterns for infrastructure services.

Finally, a few studies collect primary data through household surveys specifically designed for evaluating subsidy incidence. These studies have been able to use income data, and they have

[6] The efficient firm model used in Chile induces efficiency through the use of incremental cost of development pricing. (Bitrán and Arellano, 2005) explain that 'in Chile, to avoid transferring the cost of inefficiencies to users, the rate setting process emulates competitive conditions by using a fictitious company that would theoretically meet demand over the next five years in the most efficient way.'

also gathered comprehensive data on asset ownership and housing characteristics to develop a wealth indicator to classify their sample in wealth quintiles[7] (Fuente *et al.*, 2016; Cardenas and Whittington, 2021). Most importantly, these surveys have not relied on back calculations to estimate households' levels of water use. Cardenas and Whittington (2021) describe the problems of the back-calculation approach: one of them is the recall bias when survey respondents self-report their electricity or water bill, and the second is the lack of accuracy in the estimation if an IBT is reduced to an average price[8].

Shared connections

An aspect that has not been much evaluated in the literature is the issue of shared connections. This is due to the type of detailed data that is needed for this type of analysis, as the researcher not only needs information on the connected account to the utility company, but also whether that account serves for one or more than one household. Few studies mention this factor and their complexities and they acknowledge than when taking this factor into account, the results would undoubtedly me more regressive (Fuente *et al.*, 2016; Cardenas and Whittington, 2021). However, no studies on the water and sanitation sector have included a detailed analysis yet to evaluate the impact of shared connected households on subsidy incidence analysis. This factor of shared connections has been only analyzed on a subsidy incidence analysis for electricity in Addis Ababa, Ethiopia. Cardenas and Whittington (2019) matched electricity utility data to a sample of surveyed households and they included in their survey questions about connection sharing, including the number of households that share the meter. For those that shared the meter, they surveyed all households that belonged to that compound to have the socio-economic data for all households sharing the meter. They found that the majority of households with shared connections were in poorer quintiles, and 80% in the poorest quintile were non-primary customers. The authors found that households with private connections for the exclusive use of family members use much more electricity than households with shared connections; however, because households with shared connections had a higher amount of combined electricity use, the tariff charged to these households would then correspond to a higher block.

1.2 Description of Subsidy Incidence Studies for Water and Sanitation Sector with Direct and Indirect Targeting

The following Table 1 presents a summary of the individual and multi-country studies that I include in the description of subsidy incidence studies in this subsection:

[7] This has been a useful tool to address issues of lack of accuracy and non-response rate on income data.
[8] When using back calculations researchers "typically use the average price paid based on the existing tariff structure to back-calculate the quantity of water or electricity used; however, if the utility deploys an IBT to calculate customers' bills, this back-calculation will not yield an accurate estimate of the quantity used by the customer" (Cardenas and Whittington, 2021).

Table 1: Subsidy Incidence Studies for Water and Sanitation Sector with Direct and Indirect Targeting

	Country & Location	Year of Study	Subsidy Mechanism	Distribution Subsidies	Errors of Exclusion & Inclusion
Abramovsky et al (2020)	Multi-country: Ethiopia, Mali, Niger, Nigeria, Uganda, El Salvador, Jamaica, Panama, Bangladesh, and Vietnam.		IBTs in 6 countries Fixed rate in 2 countries Mixture of VDT with fixex rate in 1 country Mixture of IBT with fixed rate in 1 country	**Across the 10 countries:** Poorest quintile: 6% Richest quintile: 56%	**Exclusion ε**: vary from 51% in Jamaica to 99% in Niger. **Inclusion ε**: vary from 39% in Panama to 99% in Niger.
Barde and Lehmann (2014)	Peru: Lima	2011-2012	4 block IBT	Leakage rate: 90% allocated to non poor households	**Exclusion ε (eligible)**: 10% **Exclusion ε (non-utility)**: 34% **Inclusion ε**: 91%
Cardenas and Whittington (2021)	Ethiopia: Addis Ababa (households connected to the electricity network and water pipeline)	2016	7 block IBT	Poorest quintile: 12% Richest quintile: 34% (water-only subsidies) Note: study also reportes water+electricity subsidies	n.r.
Foster (2004)	Argentina (Urban & metropolitan areas)	2002	Means-tested subsidy	Concentration coefficient: National level: - 0.15 Varies widely: - 0.80 to 0.28	**Exclusion ε**: 73% **Inclusion ε**: 44% (calculated from simulation)
Foster and Araujo (2004)	Guatemala	2000	Flat rate up to 15, 25 or 40 m3 and subsequent consumption by volumetric rate	n.r.	n.r.
Foster and Yepes (2006)	Multi-country (Latin America & Caribbean): Colombia, Bolivia, Costa Rica, Peru, Guatemala, Panama, Chile, Brazil.		IBTs in almost all 17 utilities analyzed (except from Cali and Medellin).	n.r.	n.r.
Fuente et al (2016)	Kenya: Nairobi	2014	4 block IBT	Poorest quintile: 16% Richest quintile: 29%	n.r.
Gomez-Lobo and Contreras (2003)	Chile and Colombia (Urban areas)	Chile: 1998 Colombia: 2003	Chile: means-tested discount Colombia: Geographically targeted scheme	Chile: - Poorest 3 deciles: 45% - Richest quintile: less than 5% Colombia: - Poorest 3 deciles: 45% - Richest quintile: ~ 15%	Large errors of exclusion in Chile. Large errors of inclusion in Colombia
Groom et al (2008)	China: Beijing	2002	3 block IBT	Most households subsidized as most consume within the lifeline block.	n.r.
Komives et at(2006, 2007)	Multi-country: Argentina, Cape verde, Chile, Colombia, Croatia, India, Nepal, Nicaragua, Mangua, Panama, Sri Lanka, Uruguay, Venezuela.		7 utilities used IBTs, Colombia used a geographically defined tariff with an IBT, Croatia used a uniform volumetric tariff, and Chile, Argentina, and Paraguay used means-tested discounts.	**Ω Targeting Estimator:** **Quantity-based mechanisms:** - Cape verde: 0.24 - Nepal: 0.56 - Bangalore: 0.66 - Sri Lanka: 0.83 **Geographic targeting:** - Bogota: 1.09 - Managua: 1.18 - Merida: 1.09 - Urban Paraguay: 1.42 **Means testing:** - Argentina: 1.23 - Chile: 1.63 - Urban Paraguay: 1.64	**Exclusion ε:** **Quantity-based mechanisms:** - Cape verde: 89.7% - Nepal: 53% - Bangalore: 60.5% - Sri Lanka: 69.5% **Geographic targeting:** - Bogota: 1.9% - Managua: 5% - Merida: 0% - Urban Paraguay: 98.8% **Means testing:** - Argentina: 76% - Chile: 78% - Urban Paraguay: 93.1%
Melendez (2008)	Colombia (Bogota)	2003 & 2007	Greographical defined tariffs with IBTs	**Poorest quintile:** (2003): 28% / (2007): 32% **Richest quintile:** (2003): 9% / (2007): 6% (water subsidies) Note: study also reports electricity subsidies	**Exclusion ε**: (2003): 6% (2007): 5% **Inclusion ε**: (2003): 85% (2007): 75%
Prokopy (2002)	India (Bangalore)	2001	IBT with 25m3 first block Public tap (free of charge)	Poorest quintile: 16% Richest quintile: 32%	n.r.
Pattanayak, and Yang (2002)	Nepal (Kathmandu)	2001	IBT with 10m3 first block Public tap (free of charge)	Poorest quintile: 10% Richest quintile: 25%	n.r.
Walker et al (2000)	Nicaragua, El Salvador, Venezuela, Panamá (Urban areas)	1995 - 1998	IBTs (various number of blocks)	**Mangua**: Poorest quintile: 17% Richest quintile: 15% **Panama:** Poorest quintile: 20% Richest quintile: 24% **Merida**: Poorest quintile: 20% Richest quintile: 12% **Cities in El Salvador**: Poorest quintile: -3.6% Richest quintile: 51%	n.r.

Studies on Quantity-based Mechanisms

The majority of studies on subsidy incidence in the water sector, either individual case studies or multi-country case studies, report that the mechanism to deliver subsidies is with quantity-based mechanisms (through the tariff structure). As well, the most common tariff structure used among these studies is the increasing block tariff (IBT), and in few other cases other types of volume differentiated tariffs.

From the nine individual case studies on subsidy incidence covered in this literature review, seven present cases of quantity-based mechanisms. These studies include cases on: Guatemala (Foster and Araujo, 2004); Bangalore, India (Prokopy, 2002); Nepal, (Pattanayak and Yang, 2002); Beijing, China (Groom *et al.*, 2008); Lima, Peru (Barde and Lehmann, 2014); Nairobi, Kenya (Fuente *et al.*, 2016), and Addis Ababa, Ethiopia (Cardenas and Whittington, 2021). All of these cases report the use of IBT with various numbers of blocks, except the case for Guatemala that used a flat rate up to 15, 25 or 40 cubic meters and subsequent consumption by volumetric rate.

This review also includes multi-country studies that evaluate the water sector: Walker *et al.* (2000); Komives *et al.* (2006); Foster and Yepes (2006), and Abramovsky *et al.* (2020). These multi-country studies also show the prevalence of quantity-based subsidy mechanisms in the water sector, as well as the prevalence of IBTs. Abramovsky *et al.* (2020) evaluated ten countries, all of which used quantity-based mechanisms. This study included Ethiopia, Mali, Niger, Nigeria, Uganda, El Salvador, Jamaica, Panama, Bangladesh, and Vietnam. Six out of these ten countries used IBTs; two countries, Nigeria and Uganda, used fixed rates; in Bangladesh some service providers charged a flat rate and others used IBT, and El Salvador used a VDT with fixed rate. Some of these countries included a value added tax on tariffs. Also, Komives *et al.* (2006) reviewed 21 countries, 13 of the studied cases were on water utilities from various countries [Refer to Table 1]. For the existing cases (not simulated) in the water sector, these authors found that seven utilities used IBTs, Colombia used a geographically defined tariff with an IBT, Croatia used a uniform volumetric tariff, and Chile, Argentina, and Paraguay used means-tested discounts. Foster and Yepes (2006) evaluated seventeen utilities from eight countries in Latin America (Colombia, Bolivia, Costa Rica, Peru, Guatemala, Panama, Chile, Brazil). They found that IBTs were almost universal in the seventeen Latin American utilities surveyed in their study (except from Cali and Medellin). Walker *et al.* (2000) analyzed some urban areas from Nicaragua, El Salvador, Venezuela and Panama, all the locations that they analyzed applied IBTs, but in various cases (Managua, Venezuela and Panama) there was some type of geographical targeting.

- *Benefit incidence analysis in quantity-based mechanisms*

In these individual and multi-country case studies, benefit incidence analysis results show that subsidies delivered through quantity-based mechanisms are regressive. The level of regressiveness vary widely among studies, with studies finding that the poorest quintile allocates the -3.6% in cities of El Salvador (meaning in this case that the poor are subsidizing the rich), 10% in Nepal, 12% in the city of Addis Ababa (only among households connected to the pipeline), 16% in Nairobi, 10% in Bangalore, among others. At the same time, in these studies the richest quintile has received the following share of subsidies: 51% in cities of El Salvador, 25% in Nepal, 34% in the city of Addis Ababa (only among households connected to the pipeline), 29% in Nairobi, 32% in Bangalore, among others [Refer to Table 1 for more details of each study]. Abramovsky *et al.* (2020) found that on average, across the ten examined low and middle-income countries, 56% of subsidies are allocated to the richest quintile, but only 6% of subsidies are allocated to the poorest quintile. They also found that the severity of regressivity varies significantly, with an average targeting performance estimator Ω value of 0.45 across all ten countries, which varies from 0.6% in Niger to 87% in Panama. Komives *et al.* (2006) in a multi-country study compared quantity-based mechanisms with administrative targeting mechanisms for cases in the water and electricity sectors. They found that every water subsidy mechanism that attempted targeting poor households based on the quantity-based mechanism has been regressive. The targeting estimator Ω for these cases have all been under 1 (between 0.24 in the case of Cape Verde to 0.83 in the case of Sri Lanka). Furthermore, quantity-based consumption subsidies have been found to be regressive, even conditional on having access and being connected to the network (Cardenas and Whittington, 2021). Finally, similar case studies on subsidy incidence for the electricity sector, all find regressive results of the beneficiary incidence analysis [See for example: Cardenas and Whittington (2019) provide a summary of cases in the electricity sector; (Komives *et al.*, 2006; Komives, Halpern, Foster, Wodon, *et al.*, 2007).

- *Errors of exclusion and inclusion in quantity-based mechanisms*

Errors of exclusion and inclusion are also common in quantity-based mechanisms. The error of inclusion is measured as the percentage of all beneficiary households that are non-poor. The error of exclusion is measured by the percentage of poor households that do not get a subsidy. The estimation of the latter presupposes also having data on the population that does not have access to connection or metering in the area. Therefore, some studies do not report this estimate, or other studies report it by taking into consideration only the customers that are part of the water pipeline network. Among the studies that report these estimates, there is a wide range of results: 34% reported in Lima (Barden and Lehman 2012); 51% in Jamaica, 99% in Niger (Abramovsky *et al.*, 2020); 53% in Nepal, 90% in Cape Verde (Komives *et al.*, 2006), among others. Similarly, the errors of inclusion are quite high, ranging from 39% in Panama to 99% in Niger (Abramovsky *et al.*, 2020) [Refer to Table 1].

From the results on quantity-based mechanisms presented in Table 1 on the distribution of subsidies among poor and non-poor, it is evident a wide range of results in their targeting performance (either explained by subsidy distribution among quintiles, leakage rate, benefit targeting performance indicator, or errors of exclusion and inclusion). Even though all of the studies on quantity-based mechanisms show regressive results, there are big differences in the subsidy incidence results. This wide variance is explained in part by differences in the economy and administration of utilities in those countries and regions, but also it is due to the fact that various studies take into consideration areas with diverse levels of connection rates. Some studies evaluate areas with a population with and without access to water pipeline connections, while there are other studies that evaluate the subsidy incidence only among the connected population. In such studies where the non-connected populations are taken into consideration, the access factor will be a key determinant of the benefit targeting performance. Studies that take into consideration rural areas, and/or urban non-connected areas, will tend to show worse targeting of subsidies to the poor population. Therefore, the access factor plays an important role in the analysis or targeting subsidies to the poor, because it is generally the poor population who are more likely to live where no water pipeline connections are available.

Various authors have also addressed the question of why quantity-based subsidies perform so poorly. Two of the key reasons include: 1) the lack of correlation between income and water consumption which makes it hard to design a tariff that excludes non-subsidization to the rich while ensuring subsidization to the poor, even less so in the presence of fixed charges, minimum consumption charges, or a high first consumption block (Whittington, 1992; Boland and Whittington, 2000; Komives, Halpern, Foster and Wodon, 2007; Whittington *et al.*, 2015), and 2) quantity based mechanisms do not fix the problems of reaching the population that does not have access to metered water connection or the issues of shared connections (Komives *et al.*, 2006; Cardenas and Whittington, 2021).

Studies on Administrative Targeting

Studies on subsidies delivered through administrative targeting are less in number than the studies of subsidies delivered through quantity-based mechanisms. Even though this fact might pose a restriction on the certainty of the conclusions about these mechanisms, it also portrays reality, as much of the developing world subsidizes residential water consumers through quantity-based mechanisms and to this date there are less cases that use an administrative type of targeting.

Administrative targeting includes means-testing and geographic targeting. In this type of targeting, the utility uses a tariff structure (it can even be IBTs or VDTs) while they target poor households through administrative identification to deliver subsidies. In this way, geographic targeting includes cases like Managua, Merida, and Panama, which have IBTs with slum discounts, or Bogota and other urban areas of Colombia, which have geographically defined tariffs with IBTs.

- *Benefit incidence analysis in administrative targeting*

Gómez-Lobo and Contreras (2003)is the first study that presented subsidy incidence results from two subsidy programs with administrative targeting. They evaluated a means-tested discount program implemented in Chile and a geographically targeted scheme implemented in Colombia. Both programs, as shown by their cumulative monetary transfer curve per centile of per capita income, are progressive (about 45 percent of subsidies are allocated to the poorest 30% of households). However, the Chilean scheme performed better in transferring more income to middle-income groups rather than to higher income groups. The Chilean program transferred less than 5% to the richest quintile, while the Colombian program transferred about 15% to the richest quintile. (Komives *et al.*, 2006; Komives, Halpern, Foster, Wodon, *et al.*, 2007) compared quantity-based mechanisms with programs of administrative selection, including cases of geographic targeting and means testing. In contrast to their results for the cases that used quantity-based mechanisms, they found that cases that have used administrative selection to target poor households in the electricity and water sectors have shown progressive results (benefit targeting performance indicator omega Ω higher than 1 in every evaluated case). Foster (2004) evaluated the case of means-tested subsidy for water and electricity in Argentina. This study was evaluated at a province-level and they found that results varied largely across provinces variation, finding concentrations coefficients in the range of -0.80 to +0.28. These results were consistent to the differences in access of the populations to public services; nevertheless, overall the concentration coefficients for both sectors tended to progressive impacts, with a Gini coefficient of -0.15 for water and a Gini coefficient of -0.37 for electricity[9]. Melendez (2008) evaluated a geographically targeted subsidy scheme in the water and electricity sectors in Colombia; she found progressive results for the analysis of Bogota, Colombia for both sectors of water and electricity. [Refer to Table 1 for further details on benefit targeting performance indicators in every study].

- *Errors of exclusion and inclusion in administrative targeting*

Even though analyzes of case studies with administrative targeting have shown more progressive results than quantity-based mechanisms, they have reported high levels of errors of exclusion and inclusion. Gómez-Lobo and Contreras (2003) reported that both programs (Chile and Colombia) had high levels of error of inclusion: in Colombia more than 80% of beneficiaries were not in the poorest quintile of income distribution, while in Chile more than 60% of beneficiaries were not in the poorest quintile of the income distribution. Also, the errors of exclusion of the Chilean program were high as this program covered about 15% of the population. In the case of Colombia, errors of exclusion were not as large, because the Colombian scheme covered a much larger share of population (close to 95%), which at the same time made its errors of inclusion of much higher magnitude. Melendez (2008) reported that in Bogota, Colombia, exclusion errors in 2007 amounted to 5% for subsidies in the water sector and 3% for subsidies in the electricity sector; she also reported that in 2007 there were still exclusion errors of 75% for both the water and electricity sectors. Foster (2004), for the case of Argentina's water sector, reported inclusion errors of 44% and exclusion errors of 73%. These were national averages, although they varied widely among provinces and metropolitan areas.

Magnitude

Very few studies report on the magnitude of the subsidies. Foster (2004) reported a spending of about USD 8 million (2002) annual cost of water subsidies. Also, Gómez-Lobo and Contreras (2003) reported that the water subsidy program in Chile in 2000 reached USD 42.5 million, which they explained represented an amount well below the cost of the universal subsidy, given that service providers experienced high losses before the reform to administrative targeting. Andres *et al.* (2019), who evaluated the magnitude of water subsidies at a global level –the majority of schemes being quantity-based mechanisms-, estimated that total subsidies for networked water and sewerage services were at around 0.5% of GDP worldwide, and over 1.5% of GDP for non-advanced economies. These results show that the magnitude of water subsidies for residential consumers represent a very high burden on public budgets. However, there is

[9] In this study, the author uses a quasi-Gini coefficient. This is a concentration coefficient bounded -1 to .1. The more progressive is the distribution of impacts, the closer the quasi-Gini coefficient is to -1.

pending analysis on the costs of water subsidy programs that compares the magnitude between quantity-based mechanisms and administrative targeting.

1.3 Conclusion

Quantity-based subsidies delivered through the tariff structure are the most commonly used mechanism of subsidization in the water sector in developing countries. In these cases, tariffs that are usually differentiated by quantity (with higher charges at higher quantity levels) are implemented under the assumption that income and water use are highly correlated. However, this relationship has proved wrong in many cases. In every study that subsidy incidence analysis has been evaluated for quantity-based mechanisms, they have shown regressive results. Warnings about adverse effects of quantity-based mechanisms for poverty alleviation goals have been reported over three decades. However, subsidization through the tariff structure is still a widely spread instrument to deliver water subsidies in the developing world.

In most cases where geographically targeted and means-tested subsidies have been implemented, these have shown progressive results. However, reported errors of exclusion and inclusion of these programs are quite significant. Further analysis on mechanisms of administrative targeting, in particular on how to combine them with tariff design regulations, what is the magnitude of these programs, and how they compare to quantity-based mechanisms, are still needed.

2. Price Elasticities of Residential Piped Water Demand in Urban Areas

As policymakers and regulators in various cities in Latin America are re-evaluating its pricing policies and subsidy schemes for piped water service provision, it is pertinent to review the literature on price responses of residential water demand. In this literature review, I present an overview of the topics that have been evaluated in this literature in the last decades, and I summarize relevant topics for future studies. I organize this review in two sections: The first section is a synopsis of the broad literature with emphasis on meta-analyses that have been developed since the late 1990s to this date. And the second section includes a review on case studies that focus on residential water demand in one location (one service provider), which has experienced relatively significant price changes, and if the study uses micro-data (household-level data). I focus on these cases to delineate the methods, conclusions, and lingering questions of studies with these characteristics. I provide a few remarks at the end of each section, and finally I conclude.

2.1 Overview of factors that impact price responses of residential water demand in developed and developing countries: Meta-analyses

To this date, five meta-analyses have been evaluated on price response of residential piped-water demand. I compare and discuss these meta-analyses for two reasons: first, they summarize quite well the spectrum of results on price elasticities, and they include the bulk of literature that use a variety of data types and methodologies. Second, these meta-analyses have quantitatively evaluated the statistical significance of factors that might impact the estimation of price elasticity of residential water demand. Therefore, they report on the type of data that might be needed for these studies, as well as on the topics of controversy and un-answered questions in this literature. I present a comparative summary of these meta-analyses in Table 2.1.

Scope of meta-analyses

The first meta-analysis on price elasticities of residential piped water demand was developed in 1997 by Espey, Espey and Shaw. They used 24 studies that yielded 124 estimates of price elasticity of demand for residential water use. Following the work of Espey, Espey and Shaw (1997), Dalhuisen et al. (2003) developed a new meta-analysis in which they expanded the database of the previous meta-analysis. Dalhuisen et al. (2003) evaluated 64 studies between 1993 and 2001 from which they derived 296 price elasticity estimates and 161 income elasticity estimates of residential water demand. Sebri (2014) evaluated 100 studies from developed and developing countries between 2002 to 2012, which yielded 638 price elasticity estimates, and 72 studies that yielded 322 estimates of income elasticity. In this meta-analysis, the author does not overlap their sample with the previous meta-analysis from Dalhuisen et al. (2003). Marzano *et al.* (2018) implemented another meta-analysis with 124 primary studies from 1964 to 2013, which yielded 615 estimates on price elasticities[10]. Finally, Jegnie, Fogartya, and Iftekhar (2021) in a recent working paper presented a meta-analysis of price and income elasticities for residential urban water demand. They used 175 studies that yielded 1,020 price elasticity estimates, and 126 studies that yielded 516 income elasticity estimates. Jegnie, Fogartya and Iftekhar (2021) also differentiated their analysis by country income level[11].

Espey, Espey and Shaw (1997) evaluated studies only of the United States. Dalhuisen et al. (2003) and Sebri (2014) did not report the number of countries included in their dataset. Marzano *et al.* (2018) reported that their dataset included 31 countries. Jegnie, Fogartya and Iftekhar (2021) included 55 countries, and they reported that only 2.5% of their price elasticity estimates corresponded to Latin American studies. The majority of their estimates were from North America (48.9%) and from the European Union (21%)[12].

Results on price elasticities and income elasticities reported in meta-analyses

As summarized in Table 2.1, meta-analyses on price responses in water demand generally report, with very few exceptions, price elasticities that are negative in sign and less than one. This means that most of the case studies report inelastic responses to price. Espey, Espey and Shaw (1997) find that price elasticity estimates range from -3.33 to -0.02, with an average of -0.51 (90% of the estimates are between 0 and -0.75). Dalhuisen et al. (2003) find a mean price elasticity of -0.41 and median price elasticity of -0.35 (st. dev. 0.86). Sebri (2014), even though he constructs an entire new dataset with more recent studies, he finds similar results to the previous meta-analyses. In this sample, price elasticities ranged from -3.054 to -0.002 with a mean of -0.365 and a median of -0.291. Marzano *et al.* (2018) find a mean prices elasticity of -0.4 and median price elasticity of -0.34 (st. dev. 0.72). Jegnie, Fogartya and Iftekhar (2021) find a mean price elasticity of -0.38, and when they correct for publication bias they obtain a mean price elasticity value of -0.27 (95% CI -0.31 to -0.23).

In regards to income elasticity, Espey, Espey and Shaw (1997) and Marzano *et al.* (2018) do not evaluate this elasticity. Dalhuisen et al. (2003) find a mean income elasticity of -0.43 and median income elasticity of 0.24 (st. dev. 0.79). In the meta-analysis by Sebri (2014), income elasticities ranged from -0.44 to 1.56, with a mean of 0.207 and a median of 0.159. Jegnie, Fogartya and Iftekhar (2021) find a mean income elasticity of 0.29, and when they correct for publication bias, they obtain a mean income elasticity value of 0.14 (95% CI -0.12 to 0.16). Also, Havranek, Irsova and Vlach (2018) in another meta-analysis on residential water demand, which only focused on income elasticities, evaluated 124 studies from 31 countries for the period between

[10] Marzano *et al.*(2018) did not evaluated income elasticities.
[11] Sebri (2014), Marzano *et al.*(2018), and Jegnie, Fogartya and Iftekhar (2021) used weighting techniques to consider that various estimates were obtained from a single study. Then, they used weights at the study level for their statistic estimates.
[12] The remaining price elasticities estimates in the meta-analysis from Jegnie, Fogartya and Iftekhar (2021), corresponded to: Middle Easter countries (9.3%), North African countries (9.1%), Australia and New Zealand (4.8%) and Sub-Saharan Africa (1.8%).

1963 to 2013. They reported income elasticities that ranged from -0.45 to 2.8 with a mean income elasticity of 0.26 and a median of 0.16.

Other reviews of water demand modeling, such as Arbués, García-Valiñas, and Martínez-Espiñeira (2003) and Worthington and Hoffman (2008), report similar findings on price and income elasticities. In summary, these meta-analyses and further reviews conclude that water demand is price inelastic, and that water consumption grows only modestly with income. The variance in results is mainly around how inelastic price is in water demand. Some of the variables that have been most important in influencing price elasticity estimation are discussed below.

Table 2.1: Comparative Summary among Meta-Analyses on Price Responses in Residential Piped Water Demand

Authors	Year	Price Elasticity	Income Elasticity	Factors of Possible Impact on Price Elasticity Estimates						
				Outdoor vs. Indoor Use	Season	Data Aggregation	Time-frame	Tariff Structure	Functional form	Structural form model
Espey et al.	1997	mean: - 0.51 range: - 0.02 to - 3.33 (90% of the estimates are between 0 and -0.75).	n.r.	◆outdoor more elastic estimates	◆summer more elastic estimates	No statistical difference	◆long-run more elastic estimates	◆IBT more elastic estimates	No statistical difference	n.r.
Dalhuisen et al.	2003	mean: - 0.41 median: - 0.35 (st. dev 0.86)	mean: 0.43 median: 0.24 (st. dev 0.79)	n.r.	◆summer more elastic estimates	No statistical difference	◆long-run more elastic estimates	◆IBT more elastic estimates	No statistical difference	◆DCC model more elastic estimates
Sebri	2014	mean: -0.365 median: -0.291	mean: 0.207 median: 0.159	◆outdoor more elastic estimates	◆summer more elastic estimates	◆micro-data more elastic estimates	◆long-run more elastic estimates	◆IBT less elastic estimates	◆Stone-Geary, semi-log and translog less elastic estimates	◆DCC model more elastic estimates
Marzano et al.	2018	mean: - 0.4 median: - 0.34 (st. dev. 0.72)	n.r.	n.r.	◆summer more elastic estimates	◆micro-data more elastic estimates	◆long-run more elastic estimates	◆IBT more elastic estimates	◆log-log more elastic estimates	◆DCC model more elastic estimates
Alemken et al.	2021	mean: - 0.38 short-run: - 0.27 long-run: - 0.45 Bias corrected estimate: - 0.27 [95% CI - 0.31 to - 0.23]	mean: 0.29 short-run: 0.36 long-run: 0.25 Bias corrected estimate: 0.14 [95% CI 0.12 to 0.16]	◆outdoor more elastic estimates	n.r.	◆statistically significant	◆long-run more elastic estimates	n.r.	◆Stone-Geary less elastic estimates	n.r.

◆ Statistical significant difference
n.r. not reported

Indoor-outdoor water use and seasonality

All meta-analyses agree that summer and outdoor activities appear to exhibit higher values (in absolute terms) of price elasticity. Espey, Espey and Shaw (1997) found that winter demand was less elastic than average demand, and summer demand was significantly more elastic than average demand. They explained that this result could be related to the fact that outdoor water uses are less necessary than other uses, especially in summer. Dalhuisen et al. (2003) reported a statistically significant seasonal dummy variable, as well as a statistical difference for winter demand which appears to be less elastic. Sebri (2014) reported higher values (in absolute terms) of price elasticity for estimation of summer water demand and for outdoor activities. Marzano *et al.* (2018) also reported that estimates relying on summer data show a more price-elastic demand. Jegniea et al. (2021) compared price elasticity estimates for outdoor and indoor demand versus total water demand and found that outdoor demand estimates were statistically different and more price elastic.

Data aggregation

Espey, Espey and Shaw (1997) and Dalhuisen et al. (2003) did not find statistically significant difference between price elasticity estimates that use disaggregated micro-data (e.g. households) versus aggregated data. In contrast to these results, Sebri (2014) concluded that the level of data aggregation is statistically significant in price elasticity estimation, and that using household data (rather than other more aggregate data) produced more elastic estimates. Sebri (2014) also found that frequency of observations, for example using aggregated water consumption, such as monthly, quarterly or yearly, as opposed to daily, tends to deflate both price and income elasticities. Marzano *et al.* (2018) reported statistical difference in the estimation with disaggregated data, both over time and across users. Jegnie, Fogartya and Iftekhar (2021) found that the aggregation level (city, state, national) versus disaggregated data (household level) was statistically significant[13].

Long-run versus short-run

All studies reported statistical differences among price elasticities estimates for short-run demand versus long-run demand analyses. Long-run elasticities are larger in magnitude. Also, Jegnie, Fogartya and Iftekhar (2021) reported mean estimates of short versus long run: short-run mean price elasticity of -0.27 and mean long-run price elasticity of -0.45.

Tariff structure and estimation technique

Espey, Espey and Shaw (1997), Dalhuisen *et al.* (2003), and Marzano *et al.* (2018) coincided in the result that the underlying tariff system is an important factor in the level of price elasticities.

[13] In Jegniea et al., (2021) meta-analysis, the direction of impact of the variable that evaluated the level of data aggregation was not discussed or reported in the estimation table results.

These three meta-analyses found that price elasticity estimates from studies that analyze IBTs show water demand to be more price elastic. However, Sebri (2014) found contrary results to other meta-analyses. He did find statistical differences of price elasticity estimates with IBTs; yet, he found that these estimates are less price elastic, rather than more price elastic. Jegnie, Fogartya and Iftekhar (2021) did not discuss the tariff structure in their analysis.

Functional form and structural vs. reduced-form model

Throughout the years, more functional forms and models of water demand have been evaluated in meta-analyses of residential water demand. For example, the two first meta-analyses evaluated only linear and log linear functional forms, while the later meta-analyses included other functional forms. Also, the evaluation of the discrete continuous choice (DCC) model was not present in the first meta-analysis of Espey, Espey and Shaw (1997), but this model was included in subsequent meta-analyses.

Espey, Espey and Shaw (1997), Dalhuisen *et al.* (2003) and Sebri (2014) reported no statistical differences of price elasticity estimates based on using linear and log linear functional forms (which are some of the most common functional forms used in the residential water demand literature). On the other hand, Sebri (2014) did find some statistical differences when using the Stone-Geary functional form, or other forms like semi logarithmic and translog. In these cases, Sebri (2014) found that price elasticities are deflated. Also, Marzano *et al.*(2018) reported statistical differences for price elasticity estimates that use the log-log specification, associated with a more elastic water demand. Jegnie, Fogartya and Iftekhar (2021) differentiated particularly for the Stone-Geary functional form (which is a functional form that allows for a subsistence level of water use), and they found a statistical difference for this functional form associated with a less price elastic demand.

In regards to the type of model, whether reduced-form or structural model, most meta-analyses did find a statistical difference of price elasticity estimates when using the DCC model, associated with a higher value of price elasticity (in absolute terms) (Dalhuisen *et al.*, 2003; Sebri, 2014; Marzano *et al.*, 2018). Espey, Espey and Shaw (1997) and Jegnie, Fogartya and Iftekhar (2021) did not evaluate this factor in their meta-analyses.

Other variables

All meta-analyses found that additional factors that impact prices elasticities of residential water demand include: climate variables (e.g. precipitation, temperature, evapotranspiration), household size, and income. Regarding income, Jegnie, Fogartya and Iftekhar (2021) finds that the type of income data used, actual income versus an income-proxy, makes a difference in the estimation of price elasticities of water demand (using an income proxy instead of actual income data is associated with less elastic demand). Also, Jegnie, Fogartya and Iftekhar (2021) differentiated price elasticity estimates by devoleped and developing countries, finding that in upper-middle income countries short-run and long-run price elasticity estimates are lower in value (in absolute terms) than in lower-midle income countries. Nonetheless, Dalhuisen *et al.*

(2003) and Sebri (2014) found ambiguos results on whether developed or deveoping countries show statistical differences in price elasticities of water demand.

Publication bias

Interestingly, some authors have included publication bias as one of the factors to evaluate in the meta-analyses. Espey, Espey and Shaw (1997) and Dalhuisen *et al.* (2003) did not analyze this factor, while Sebri (2014), Marzano *et al.*(2018), and Jegnie, Fogartya and Iftekhar (2021) did evaluate it. Only Jegnie, Fogartya and Iftekhar (2021) found evidence of publication bias, for both price and income elasticity estimates. These authors explain that "the presence of publication bias works to push the elasticity estimates away from zero, but the impact is modest."

❖ ***Remarks from the Evaluation of Meta-Analyses***

The meta-analyses reviewed in this section show that throughout the years, the number of papers collected, their geographical scope, and estimation techniques have increased. These changes in meta-analyses indicate that more studies on water demand have been published, and that further techniques have been developed to analyze residential water demand. Interestingly, results on price elasticity have not varied much throughout the years.

Most meta-analysis agree that the following factors impact estimates of water demand price elasticities: time-frame, seasonality, whether there is differentiation among outdoor or indoor uses of water, climate variables, household size. On the other hand, there are other factors for which there is no consensus, either about the impact on the estimates of price elasticity, or about the direction of the impact. These factors include: the type of tariff structure, functional form, structural or reduced-form model, the level of aggregation, and whether there is publication bias in the estimates. Careful inclusion of the variables that have shown to impact price elasticity estimates is necessary. On the other hand, the factors where there has not been consensus show possible areas of future research to further analyze them in new case studies. Finally, it is evident the need of more case studies and published reported results on this topic for developing countries.

The next section of this review looks at particular case studies in the literature.

2.2 Case studies on the impact of price changes of piped water evaluated in one location with micro-data

When estimating water demand price responses, one of the most important challenges of empirical research is the availability of data with enough variation in prices over the period of analysis, as well as the availability of data before and after such price changes. These factors impact the identification strategy, especially given concerns about unobserved customers' heterogeneity. Therefore, it is best to evaluate periods of relatively significant price changes (e.g. rate increases beyond inflation, subsidy policy revisions), as well as modifications of tariff structures. In this subsection, I identify this type of case studies in the literature, which used data that covered a period of significant price variation. Also, I restrict this review to particular case studies of residential piped water demand for urban areas, which relied on data of a single location (single water provider), and which use micro-data (account/household-level data). I present a summary of the reviewed cases in Tables 2.2 and 2.3, which organize case studies in chronological order.

As shown in Table 2.2, there are relatively limited studies in the peer-refereed literature that have been implemented to capture significant price changes for an urban location (e.g. a city, county, or metropolitan area) and that use micro-data for their analyses. The studies that are found in the literature are especially from developed countries, particularly United States, Spain, Australia, Kuwait. These studies have been implemented since 1979 to this date. All of these cases have evaluated increasing block tariffs, or a change from another tariff structure (either flat rate, uniform volumetric tariff, or decreasing block tariff) to an IBT.

The case studies that base their analysis of water demand price elasticities on relatively significant price variation include studies of Danielson (1979), Agthe and Billings (1987), Arbués, Barberán, and Villanúa (2004), Klaiber et al. (2014), Clarke, Colby, and Thompson (2017). Danielson (1979) evaluated price elasticities in the area of North Carolina for a 5-year period, 1969-1974, where the first block (block that comprised most consumers) changed about 56% in less than two years. Agthe and Billings (1987) evaluated price elasticities for a 9-block IBT implemented in Tucson, Arizona during the period 1974-1981. Even if the consumption blocks did not change during the study period, water charges during these years ranged from -26% to 92% with increases and decreases that differed by block of consumption, season, and year. Klaiber *et al.* (2014) evaluated a 2-block IBT in the Phoenix urban area during a 4-year period, when the water utility implemented seasonal and annual changes in prices. Marginal price changed several times in the study period, and there was an increase in the marginal price for the highest consumption block of 73% in the overall period. Also, in this case, the quantity level of the higher block changed between seasons. Finally, Clarke, Colby and Thompson (2017) evaluated the case of Tucson, Arizona for a10-year period, where price levels of the 4 blocks of the IBT changed either seven or eight times during the study period.

Also, there is one additional case, in which the source of price variation was not price increases per-se, but the tariff itself. Arbués, Barberán, and Villanúa (2004) evaluated the case of Zaragoza, Spain during a 3-year period. During the study period, Zaragoza used a volume charge that was applied according to a progressive linear tariff of 205 average prices, elaborated on the basis of each dwelling's daily average consumption[14].

The remaining studies described in Table 2.2 correspond to cases of changes in tariff structure or a combination of a tariff structure and price changes. These studies include: Nieswiadomy and Molina (1989), Hewitt and Hanemann (1995), Pint (1999), Kenney et al. (2008), Nataraj and Hanemann (2011), Abrams et al. (2012), Baerenklau, Schwabe, and Dinar (2014), Wichman (2014), Pérez-Urdiales, García-Valiñas, and Martínez-Espiñeira (2014), Asci, Borisova, and Dukes (2017).

Nieswiadomy and Molina (1989) evaluated price elasticities for the city of Denton, Texas for a 10-year period, in which there was a change of tariff structure from decreasing block rate to IBT. Hewitt and Hanemann (1995) used the same dataset from Denton, Texas from Nieswiadomy and Molina (1989) in order to do a similar analysis but with a different model. Pint (1999) analyzed water demand price responses of Alameda County, California for a 10-year period, in which the utility changed from uniform volumetric tariff to IBT. Kenney et al. (2008) evaluated the case of Aurora, Colorado for a 9-year period, in which the utility changed from a flat rate to an IBT. Nataraj and Hanemann (2011) evaluated the case of Santa Cruz, California, and estimated price elasticites for a specific point in time when the IBT was changed from 2-block to 3-block IBT. Abrams *et al.* (2012) evaluated a change from uniform volumetric tariff to an IBT that was implemented in Sidney, Australia. Abrams *et al.* (2012) did not use micro-data perse in the estimations, but aggregated household-level data by several household characteristics (tenancy, dwelling type -property size- and participation in a water appliance efficiency program). Baerenklau, Schwabe and Dinar (2014) evaluated the case of a water provider in southern California, with data for a 10-year period, during which the tariff structure changed from uniform volumetric tariff to household specific water budgets. Wichman (2014) evaluated the case of Chapel Hill, North Carolina, a city that in 2007 changed from uniform volumetric tariff to an IBT. Pérez-Urdiales, García-Valiñas and Martínez-Espiñeira (2014) evaluated the case of Granada, Spain for a 3-year period in which the IBT was modified from a 5-block IBT to a 4-block IBT, and there were changes in block-levels of consumption and block prices. Asci, Borisova and Dukes (2017) analyzed the case of Central Florida with data of about 6-year period during which there as a change from 4- block to 5-block IBT.

Changes in prices and/or price structures in these case studies enabled researchers to evaluate water demand price elasticities, as they had enough variation in the explanatory variable of interest. In the next paragraphs, I describe the data type, estimation models, results in estimated price and income elasticities, and other variables used in these studies.

Data used in reviewed case studies

In general, these studies have used panel data for either the population or samples of residential customers provided by a water utility. The periods of analysis have varied between three and eleven years. These authors have had access to water use records from the water utility itself.

[14] This tariff implied that "all the units recorded on the meter were paid for at the same price, which was given by the average price corresponding to the last unit consumed." In other words, this was a type of volume differentiated tariff.

Generally, water consumption are monthly records, but in few cases, they are bi-monthly or quarterly records. In various of these case studies, the municipal water provider has not only shared water consumption and rate schedule information, but they have also shared customer socio-demographic information (Nieswiadomy and Molina, 1989; Hewitt and Hanemann, 1995; Pint, 1999; Abrams *et al.*, 2012; Baerenklau, Schwabe and Dinar, 2014). Other studies have used other sources for their socio-demographic variables, including census data, information from tax records, property appraisers or the city's property registry (Danielson, 1979; Arbués, Barberán and Villanúa, 2004; Kenney *et al.*, 2008; Nataraj and Hanemann, 2011; Klaiber *et al.*, 2014; Asci, Borisova and Dukes, 2017; Clarke, Colby and Thompson, 2017). Few other studies have also used household survey or interviews, these are generally studies that have relied on samples from the population (Danielson, 1979; Agthe and Billings, 1987; Pérez-Urdiales, García-Valiñas and Martínez-Espiñeira, 2014).

Table 2.2: General Information: Studies on Impact of Price Changes on Residential Water Demand (micro-data & one location)

Authors	Year	Location	Water Tariff	Data Type	Source of Price Variation
Danielson	1979	Raleigh North Carolina	IBT (most residents consume in the first block)	Consumption: administrative monthly water use records for 261 residential consumers. Socio-demographics: from tax records and personal interview. Period: 1969-1974	Price changes: -> First block price changed: 35% increase in 1972 6% increase in 8/1973 15% increase in 12/1973
Agthe and Billings	1987	Tucson, Arizona	9-block IBT	Consumption: administrative monthly water use records. socio-demographics: household survey Period: 1974-1981	Price changes: -> Changes differed by block of consumption, season and year. -> Changes ranged from -26% to 92% in study period
Nieswiadomy and Molina	1989	Denton, Texas	DBR and IBT	Consumption: administrative monthly water use records for a random sample of 101 customers. socio-demographics: administrative records. Period: 1976-1985.	Tariff structure changes: - Number of blocks - Structure: from DBR to IBT
Hewitt and Hanemann	1995	Denton, Texas	DBR and IBT	Consumption: administrative monthly water use records for a random sample of 101 customers. socio-demographics: administrative records. Period: 1976-1985.	Tariff structure changes: - Number of blocks - Structure: from DBR to IBT
Pint	1999	Alamadeda county, California	Uniform volumetric tariff and IBT	Consumption: administrative bi-monthly water use records from 599 single-family households. socio-demographics: administrative records. Period: 1982-1992	Tariff structure changes: - Structure: from uniform volumetric tariff to IBT
Arbués et al.	2004	Zaragoza, Spain	Fixed charge and + volumetric tariff	Consumption: administrative water use records of 10 time obvs for random sample of 1,596 consumers. socio-demographics: property value recorded in the Zaragoza Urban Property Register, and other data from the Zaragoza City Council. Period: 1996-1998	Price variation from: -> Progressive linear tariff of 205 average prices, elaborated on the basis of the daily average consumption of each dwelling.
Kenney et al.	2008	Aurora, Colorado	Flat rate and IBT	Consumption: administrative monthly water use records on single-family customers period. Socio-demographics: from utility and census data. Period: 1997-2005	Tariff structure and price changes: -> Change from flat rate to IBT -> For the highest blocks price change accounted for about 400% increase in the study period.
Nataraj and Hanemann	2011	Santa Cruz, California	IBT	Consumption: administrative bi-monthly water use records for all households served by the Santa Cruz Water Department. Socio-demographics: census data. Period: 1990 - 2000.	Tariff structure changes: -> Change from 2 blocks IBT to 3 blocks IBT
Abrams et al.*	2012	Sidney	Uniform volumetric tariff and IBT	Consumption: administrative quarterly water use records for **subsets of households.** Period: 06/2004 -06/ 2009	Tariff structure and price changes: -> 2-block IBT applied since October 2005 -> Rates increased in real terms by over 45% in study period
Baerenklau et al.	2014	Southern California, USA	Uniform volumetric tariff & IBT with water budgets	Consumption: administrative monthly water use records for13,000 singly family households. Socio-demographics: administrative records. Period: 2003-2012	Tariff structure changes: -> Change from uniform volumentric tariff to household-specific water budgets (with 4 blocks)
Klaiber et al.	2014	Phoenix metropolitan area	IBT and seasonal pricing	Consumption: administrative monthly water use records for 600 customers. Socio-demographics: by censu block. Period: 2000 - 2003	Price changes: -> Marginal price changed several times in the study period (seasonal and annual changes) -> Increase in marginal price for the highest water block of 73% study period.
Wichman	2014	Chapel Hill, North Carolina	IBT	Consumption: administrative monthly water use records for residential customers in Chapel Hill. Period: 2007	Tariff structure changes: -> From uniform volumetric tariff to IBT
Pérez-Urdiales et al.	2014	Granada, Spain	IBT	Consumption: administrative bi-monthly water use records for 1,465 customers. Socio-demographics: household survey. Period: 2009 - 2011	Tariff structure and price changes: -> Number of blocks change -> Block prices revised
Asci et al.	2017	Central Florida	IBT	Consumption: monthly water use records for 195 customers randomly selected. Socio-demographics: county property appraiser information. Period: 01/2003- 05/2009	Tariff structure changes: -> Change from 4 blocks IBT to 5 blocks IBT in October 2005
Clarke et al.	2017	Tucson, Arizona	IBT	Consumption: monthly water use records for single-family customers. Socio-demographics: assessed home values from county's office and annual IRS tax return by zip code. Period: 07/2001 - 06/2011	Price changes: -> Price levels of the three highest tiers were adjusted 8 times, and the price of the lowest tier was adjusted 7 times during study period.

IBT: Increasing Block Rate, DBR: Decreasing Block Rate; VDT: Volumetric Differentiated Tariff
* Abrams et al. 2012 did not use micro-data perse, but it aggregated the data by several characteristic (tenancy, dwelling type -property size- and participation in water ppliance efficiency program).

Estimation models

Table 2.3 provides a summary of the estimation technique used in the case studies reviewed in this section. A series of structural and reduced-form models have been estimated. In general, reduced-form models address endogeneity of prices with instrumental variables and the estimation is undertaken with parametric or semi-parametric methods (e.g. 2SLSQ, 3SLSQ, GMM) (Agthe and Billings, 1987; Nieswiadomy and Molina, 1989; Arbués, Barberán and Villanúa, 2004; Kenney *et al.*, 2008; Abrams *et al.*, 2012; Asci, Borisova and Dukes, 2017). Other studies have used structural models, especially the DCC, a model that was developed by Hewitt and Hanemann (1995). This model has been prized because of its theoretical background when capturing responses to marginal prices and consequent aptitudes for welfare analysis. In the studies reviewed in this section, Hewitt and Hanemann (1995), Baerenklau, Schwabe and Dinar (2014), Pint (1999) use this model. Even if Hewitt and Hanemann (1995), using the DCC model, estimated price elasticites that were higher than general estimates in the literature, subsequent studies that have used this model have obtained lower estimates around 0.20 and 0.70. [Refer to Table 2.3][15].

Olmstead (2009) analyzed and compared reduced-form and structural models of water demand under non-linear prices, using Monte Carlo experiments. She found that both models, the IV and DCC, estimated both price and income elasticity with bias. Also, she did not have a conclusion about the best choice among these models for price and income elasticity estimations.

Another estimation technique, which was developed for evaluating responses to marginal prices, is the Regression Discontinuity (RD) model. Nataraj and Hanemann (2011) used this quasi-experimental method for the first time to evaluate price elasticities for water consumption. Later, Wichman (2014) also implemented a RD design with sharp or fuzzy methods. These studies have used the fact that a change in tariff was implemented, specifically a new block was created, and therefore, they have estimated the price elasticity at that point (threshold) of price change.

Price specification and functional forms

The specification of the price variable in residential water demand models have had a broad discussion in the literature (see for example, Arbués, García-Valiñas, and Martínez-Espiñeira (2003); Worthington and Hoffman (2008)). As shown in Table 2.3, various studies specify their model with marginal price, average prices, or the Taylor-Nordin specification[16]. In the literature, there has been much discussion about what price specification to use. This debate has also become an empirical question; thus, various studies estimate water demand with both (marginal and average) price specifications for comparison [Refer to Table 2.3].

[15] Another study that was not included in this review, because of its analysis of various utilities, is worth mentioning. Olmstead, Michael Hanemann, and Stavins (2007) used data from 1,082 households in 11 urban areas in the United States and Canada served by 16 public water utilities. In their study they find evidence that price elasticity appears to differ between uniform and block rate price structures. They also obtain elasticities of the DCC model between -0.30 to -0.60.

[16] Taylor (1975), and later Nordin (1976) building on Taylor's argument, proposed a price specification that includes marginal price and an expenditure differential variable.

Regarding the functional forms, as noted earlier, the most common functional forms have been double log and linear, as evident in Table 2.3. However, the functional form of Stone-Geary has also gained some attention in the broader literature and in case studies with micro-data, especially when there is an interest on identifying a threshold of subsistence level of water.

Results in estimated price and income elasticities

Similarly, to the results of the meta-analyses presented in the first section of this review, results on price and income elasticity for these sub-group of studies on residential water demand, show once again that water is price inelastic and that income elasticity of water demand is minimal. Some of these studies have differentiated price elasticities by season (Danielson 1979; Pint 1999; Klaiber et al. 2014). Interestingly, only Danielson (1979) found similar results as what was common in the meta-analyses. While, contrarily to the meta-analyses' results, Pint (1999) and Klaiber et al. (2014) found that water demand is less price elastic in summer than in winter. The authors of these studies indicated that this result was logical, as customers are less responsive to prices during dry conditions. Also, Agthe and Billings (1987) differentiated by income group, reporting that the high income group is less price elastic. Kenney et al. (2008) also differentiated by low, middle, and high-water users, reporting that water demand of high-water users is more price elastic.

Other variables

The variables that are most commonly used as controls include weather variables, including temperature, precipitation, and evapotranspiration; income or proxies to income, such as appraised house/property values; housing characteristics, including number of bathrooms, number of rooms, swimming pool, lot size, yard vegetation, dwelling type, tenancy status; and demographic variables, such as age of household members (particular attention is paid to older members and children), education, ethnicity, environmental concern and conservation habits [Refer to Table 2.3 for details of each study].

Table 2.3: Estimation & Results: Studies on Impact of Price Changes on Residential Water Demand (micro-data & one location)

Authors	Year	Model Estimation				Results Price Elasticity	Results Income Elasticity	Other variables
		Estimation Technique	Functional form	Price Variable	Dynamic			
Danielson	1979	OLS adjusted for serial correlation	log-log	Marginal price	no	-0.27 Winter: -0.30 Summer -1.38	-0.35	Rainfall, temperature, house value, Hh size
Agthe and Billings	1987	2SLSQ and IV Simultaneous equation	Linear	Taylor-Nordin price specification	No	- 0.565 for low income group to - 0.397 for high income group	n.r.	ET, income, swimming pool, Front yard/back yard vegetation, Hhs size
Nieswiadomy and Molina	1989	OLS, 2SLSQ and IV	Linear	Taylor-Nordin price specification	No	range -0.36 to -0.86	range -0.14 to -0.20	Income proxy: apprasied house value; Weather variable: ET minus precitpitation; Lawn size, house size
Hewitt and Hanemann	1995	DCC	log-log	Marginal price	No	-1.58	0.15	Lawn size, weather, bathrooms, house size, billing days, income proxy: apprasied house value
Pint	1999	Fixed-effects and Various Maximun Likelihood models (with various error specifications, DCC)	Linear	Average price	No	summer: range 0-0.20 to -0.47 winter -0.33 to -1.24 (estimates with the two error correction estimation)	n.r.	Hh sieze, lot size, precipitation, temperature
Arbués et al.	2004	2SLSQ with IV Dynamic panel	semi-log	Average price	yes	ranges from (-0.029) to (-0.058)	ranges from 0.074 to 0.208	Hh size, collective hot water service, property value
Kenney et al.	2008	Fixed effects with IV	log-log	Average price	No	All: -0.60 Low users: -0.34 Middle users: - 0.57 High users: -0.75	n.r.	Temperature, precipitation, blockrate, rebates, price-restriction (interaction term)
Nataraj and Hanemann	2011	Regression Discontinuity Difererence in diference	Linear	Marginal price	No	-0.12 local price elasticity for Hhs near the 40-CCF cut-off (short run)	n.r.	Population density, housing density, income, house ownership, house age, # rooms, # bedrooms, Resident age, # residents, weather controls
Abrams et al.*	2012	2SLSQ with IV ARDL model with GMM	semi-log	Average price	Yes	Short-run: - 0.05 Long-run: -0.11	n.r.	Property size, dwelling type, tenancy status, participation water-appliance efficency programme, temp., ET, season
Baerenklau et al.	2014	DCC & Reduced form	log-log	Average price	no	Uniform Rate Model: -0.76 Block Rate Model: -0.58	Uniform Rate Model: 0.16 Block Rate Model: 0.05	ET, income, Hh size, irrigated area, education, seasonal controls, time trend, conservation requests (from utility)
Klaiber et al.	2014	Linear model using a difference in an order statiscis as the dependent variable.	Linear	Marginal price	No	Normal to Normal year: Winter: -1.83 to -1.41 Summer: - 0.99 to -0.40 Normal to Dry year: Winter: -1.57 to -0.97 Summer: -0.31 to -0.12	n.r.	Temperature, precipitation
Wichman	2014	Regression Discontinuity Difererence in Diference	Linear	Average price and Marginal price	No	range -0.43 to -1.14	n.r.	ET, temperature
Pérez-Urdiales et al.	2014	Latent class model with a two stage control function	no assumed functional form	Average price	No	range -0.34 to - 0.50 (only significant for 2 groups of the 4 groups estimated with the Latent Class model)	0.03 (only significant for 1 group of the 4 groups estimated with the Latent Class model)	Hh inocme, house ownership, Hh size, index conservation habits, # electrical appliances, index env. concern, age Hh member (65+ & 16- yrs), knowledge tariff structure
Asci et al.	2017	3SLS and simulataneous equations	Linear	Taylor-Nordin price specification	Yes	ranges between –0.07 and –0.14	n.r.	irrigation requirement (calcuated with weather variables), age of a house, #bathrooms, property value, total property size
Clarke et al.	2017	Fixed effects and heteroskedastic consistent standard errors	Stone-Geary	Average price and Marginal price	no	-0.17	n.r.	# days billing cycle, # rainy days & ET, proportion of hispanic residents, Hh size Variables of age Variable of education

2SLSQ: Two Stage Least Squares; 3SLSQ: Three Stage Leas Squares; DCC: Discrete Choice Continuous Model; ARDL: Autoregressive Distributed Lag Model; GMM: Generalized Method of Moments
Hh: household; n.r.: not reported

❖ ***Remarks on the Evaluation of Specific Case Studies***

The review of these case studies shows that analyses that use micro-data (household level data) have the opportunity to thoroughly evaluate the heterogeneity in consumers in relation to price elasticities. Various studies reviewed in this subsection, including Nataraj and Hanemann (2011), Asci, Borisova and Dukes (2017), Agthe and Billings (1987), Kenney *et al.* (2008), Pérez-Urdiales, García-Valiñas and Martínez-Espiñeira (2014), differentiate price responses by customer classifications, either income, level of water use, or even by non-previously identified groups with a latent class model. Additionally, studies with panel data that cover relatively significant price changes provide the opportunity to compare various models and estimation techniques. Hewitt and Hanemann (1995), Nataraj and Hanemann (2011), Wichman (2014), Pint (1999), Pérez-Urdiales, García-Valiñas, and Martínez-Espiñeira (2014) are good examples of studies that have compared either estimation techniques or variables specifications.

Even though studies of relatively significant changes in prices are good opportunities to evaluate price elasticity, these results should be taken with thoughtfulness when evaluating pecuniary policies. This is because pricing policies rarely (or never) can maintain frequent significant price changes and/or for long periods. Hence, long-run price elasticity estimates and the duration of responses to price changes are key components of the evaluation of pecuniary policies.

2.3 Conclusion

The literature on price responses in residential piped-water demand has shown that households do not respond strongly to changes in water price. However, two questions that should be asked when developing new studies include: 1) how well is the estimation model capturing the price response of residents from a particular urban area? (e.g. are key factors that influence price elasticity being included in the model? And 2) how heterogeneous is the population of such location, and whether the proposed model is evaluating and capturing such heterogeneity? The latter question is best evaluated when micro-data is available.

The literature on residential piped-water demand is still evolving and assessing improved ways to model residential water demand, including aspects and comparisons of functional forms, price specifications, and estimation techniques. Further research, especially from low-middle income countries, is necessary to have enough empirical evidence from other parts of the world, as well as to investigate the particularities of price responses of residential water demand in specific locations. Differences in weather conditions, cultural habits on water use, spatial dispersion/density of the urban residents, availability of water resources, policies already in force, among other factors, make of each location a unique evaluation.

3. Relations between Population Access to Piped Water & Sanitation and Human Health Impacts

In this review, I look at the relation between water security and human health impacts, with a focus on COVID-19. First, I provide a summary of the general framework that the literature has drawn for the links between water security and health. In the second section, I provide a summary of what has the literature analyzed on the relation between housing conditions, socio-economic determinants and COVID-19 human health impacts. In the third section, I summarize the few studies that have quantitatively evaluated relations between access to piped water and sanitation and COVID-19 incidence, mortality, and fatality rates. To this date, only correlation has been studied between access to piped water/sanitation and COVID-19 incidence and mortality impacts. In the fourth section, I select various studies that have analyzed causality between access to piped water and sanitation and other health issues. The purpose of the last section is to exemplify the type of data and methodologies that have been used in studies that attempt to isolate the impact of piped water access on health variables. Finally, I conclude in the fifth section.

3.1 General Framework on the Links between Water Security and Health

Various systematic reviews and meta-analyses have recurrently provided evidence of the relation of water security on various aspects of human health. Benova, Cumming, and Campbell (2014) presented a meta-analysis where they found evidence of association between water and sanitation environments and maternal mortality after adjusting for confounders. Celik et al. (2008) presented a systematic review where they conclude on the association between water quality, particularly arsenic in drinking water, and lung cancer. Waddington and Snilstveit (2009) presented a systematic review where they conclude on the association between water, sanitation and hygiene (WASH) interventions and diarrhea. Darvesh et al. (2017) and Wolf et al. (2018) implemented a systematic review and a meta-analysis, respectively, and found evidence on the effects of WASH interventions on childhood diarrhea. Taylor et al. (2015) presented a systematic review on WASH interventions impacts on cholera. Pruss-Ustun et al. (2019), Mbakaya, Lee, and Lee (2017), and Rabie and Curtis (2006) implemented systematic reviews and reported on the association of handwashing and respiratory infections.

Even though these reviews and meta-analyses have corroborated the evidence on relations between water security and health, this literature has also identified the need for more robust analyses and for studies that evaluate medium and long-run effects. Various authors of systematic reviews and meta-analyses have stated that there is a clear need for more careful impact studies evaluating a wider array of WASH interventions, especially with robust methodologies, in order to understand any causal relationships (Waddington and Snilstveit, 2009; Ramesh *et al.*, 2015; Taylor *et al.*, 2015). Waddington and Snilstveit (2009) stated that, *"while there is a wealth of trials documenting the effectiveness of water treatment interventions, studies conducted over longer periods tend to show smaller effectiveness and evidence suggests compliance rates and therefore impact may fall markedly over time."* Moreover, systematic reviews and meta-analyses have also indicated that reliability of results are generally related to various factors: type of intervention, whether the WASH intervention has been evaluated together with behavioral responses, and methods used to evaluate impacts (only some methods are able to use experimental settings and few are able to be designed with blind settings). Also, the inclusion of health-data based on laboratory results and not only self-reported data is valued in these studies, as it increases results' reliability.

Regarding respiratory infections, the evidence from the literature on a direct impact of water security on respiratory diseases is inconclusive. Respiratory infections have not been reported as the main diseases resulting from water security issues. Actually, Kosec (2014) when analyzing child health implications of privatizing Africa's urban water supply (using data of 39 African countries during 1986–2010) found that privatization of water supply decreases diarrhea among urban-dwelling; however, she did not find that privatization of water supply affects respiratory illnesses. On the other hand, systematic reviews in developed and developing countries (Rabie and Curtis, 2006; Mbakaya, Lee and Lee, 2017) did find association of WASH on health outcome of respiratory infections. The WASH component that they used was specifically hand hygiene (washing hand with soap or sanitizer). Yet, both reviews stated that further evidence is needed especially with more rigorous analytical methods.

Additionally, and to frame the topic of water security and COVID-19, Howard et al. (2020) reviewed the role of water, sanitation, and hygiene on disease emergence, previous outbreaks, combatting COVID-19, and in preparing for future pandemics. They identified key preventive areas that will contribute to disease control, particularly the provision of reliable and continuous piped water for all households and settings, as well as hygiene promotion programs that would be supported by behavioral science and which would be adapted to high-risk populations (such as the elderly and marginalized) and various settings (such as healthcare facilities, transport hubs and workplaces).

Finally, Paudel et al. (2021) recently presented a systematic literature review looking at papers that study particularly the nexus between water security and public health and that were published between 2008 and 2021. They looked at how health has been incorporated as a dimension in the existing water security frameworks. Various illnesses were recognized as direct impacts, being diarrhea the most prevalently studied in the ambit of water security. Also, indirect factors of the nexus of water security and health included poor accessibility and availability of water resources in terms of time and distance, as these factors cause mental illnesses. Water quality and mismanagement of water supply-related infrastructure were identified as main concerns in studies from developing countries.

3.2 Socio-Economic and Housing Conditions and COVID-19 Health Impacts

Since the COVID-19 pandemic started spreading globally, there have been various articles that presented empirical analyses on the relation of COVID-19 incidence and mortality rates to socio-economic characteristics and housing conditions. Scholars and researchers have had special interest in evaluating how sociodemographic factors may have contributed to disparities in the impact of health-related issues that affect populations.

Even long ago before the COVID-19 pandemic, various authors have looked at the relation of social inequalities and health. Seminal work on the importance of socio-economic disparities in mortalities include the studies of Phelan, Link, and Tehranifar (2010), Phelan et al. (2004), Phelan and Link (2013), Link and Phelan (1995), who use fundamental case theory to evaluate socioeconomic status as a fundamental cause of mortality disparities. In this theory, these authors proposed that *"socio-economic status embodies an array of resources, such as money, knowledge, prestige, power, and beneficial social connections that protect health no matter what mechanisms are relevant at any given time"* (Phelan, Link and Tehranifar, 2010). Link and Phelan (1995) proposed that socioeconomic status is a "fundamental cause" of mortality disparities. Phelan et al. (2004) identified a situation in which resources should be less helpful in prolonging life, and developed the following hypothesis to test: *"For less preventable causes of death (for which we know little about prevention or treatment), socioeconomic status will be less strongly associated with mortality than for more preventable causes."* They tested this hypothesis with the National Longitudinal Mortality Study which matched the Current Population Survey samples to the National Death Index to determine occurrences and causes of death in a follow-up period of approximately nine years (with a number of observations of 370,930). And their results supported their hypothesis.

Other authors have also evaluated socio-demographic factors and their effect on health. Do and Finch (2008) evaluated the link between neighborhood poverty and health, using a nationally representative sample of the nonimmigrant US population from the Panel Study of Income Dynamics (1980–1997) in which respondents rated health. They adjusted for baseline characteristics observed just prior to the measurement of neighborhood context, and used a combined propensity score and regression strategy, as well as fixed-effects modeling to account for unobserved non time-varying heterogeneity. Their results showed significant estimates of neighborhood poverty showing evidence of a causal link of the neighborhood context to health. Dye et al. (2009) evaluated the differences in national trends in tuberculosis incidence in 134 countries, from 1997 to 2006, and whether these trends could be attributable to the tuberculosis control programs, or to biological, social, and economic factors. One of their most relevant results was that the disease rate declined more quickly in countries that had a higher human development index, lower child mortality, and access to improved sanitation. Clouston et al. (2016) explained why the association between socioeconomic status (SES) and mortality has persisted across places and times and provided an analysis with historical context. They formulated a hypothesis about how diseases transit through four stages: (1) *natural mortality*, characterized by no knowledge about risk factors, preventions, or treatments for a disease in a population; (2) *producing inequalities*, characterized by unequal diffusion of innovations; (3) *reducing inequalities*, characterized by increased access to health knowledge; and (4) *reduced* *mortality/disease elimination*. Based on data of disease-specific mortality counts at the county level in the United States, they illustrated that social inequalities exist in incidence rates of many diseases, and that the cause, extent, and direction of inequalities change systematically in relation to human intervention. Then, they highlighted the role of stage duration in maintaining social inequalities in cause-specific mortality.

Regarding analysis on COVID-19, Freire de Souza, Machado, and Do Carmo (2020) evaluated the relation of social determinants to incidence, mortality, and case fatality rates of COVID-19 in Brazil, in 2020. They used bivariate spatial correlation and multivariate and spatial regression models (spatial lag model and spatial error models), finding some indications of association on confirmed cases and low human development. Kamis et al. (2021) used county-level data on household overcrowding to evaluate its links to COVID-19 mortality in the U.S. They found evidence that the percentage of overcrowded households was a strong predictor of COVID-19 mortality during later periods of the pandemic, even after controlling for poverty at the county-level. Clouston, Natale, and Link (2021) analyzed the link between socioeconomic inequalities and the spread of COVID-19 in the United States. They used county-data on daily COVID-19 incidence and mortality, and merged these data with census data on socio-economic status (SES) and various confounders, including Black race, Hispanic ethnicity, age, gender, and urbanicity. These authors used survival analyses and Poisson regression, and their results showed that, at an early stage of the pandemic, higher SES was associated with incidence of index cases; however, as social distancing took place, inequalities in SES inverted so that growth in incidence and fatality rates were higher in poorer counties. De Groot and Lemanski (2021) evaluated how pre-existing inequalities on access to basic infrastructure in South Africa impacts the way population with such inequalities respond to public health advice. Similar to the evidence from Clouston, Natale, and Link (2021), these authors also reported a “shift”, where initially the virus spread in wealthier neighborhoods[17], but over time the virus began to have a larger impact in low-income communities[18].

Other authors that evaluate the components and scope of further housing conditions, like energy insecurity, include: (Cook *et al.*, 2008; Jacobs, 2011; Hernández, 2016; Boateng *et al.*, 2021).

[17] The authors mentioned that the initial larger spread of the virus in wealthier neighborhoods was a direct consequence of European travel.

[18] Other authors that have reported on the relation of COVID-19 mortality and incidence rates to socio-economic and housing conditions, include (Stokes *et al.*, 2021; Xu *et al.*, 2021; Zelner *et al.*, 2021).

3.3 Relation of Access to Water/Sanitation and COVID-19 Incidence and Mortality

To this date, there are very few studies that focus particularly on the relation between access to piped water and/or sanitation and COVID-19 incidence and mortality. Two of these studies have been published, while the other two are working papers. Also, these studies have only evaluated correlation; causal evaluations on this question have not been reported yet in the literature. I present a summary of these studies in Table 3.1, and I describe and discuss them in the next paragraphs.

Ahmad et al. (2020) evaluated the association of household conditions to COVID-19 mortality and incidence rates. Amankwaa and Fischer (2020) in a working paper presented a very brief analysis on the correlation between COVID-19 fatalities and poor WASH (Water, Sanitation and Hygiene) services. Hyde (2021) in a working paper reported an analysis of the association of risk of exposure to drinking water contaminants and COVID-19 case fatality rate. Finally, Silva et al. (2021) evaluated the association of access to sanitation and COVID-19 incidence rates.

All of these studies have been evaluated at the aggregate level (county, municipality, or country) and the period of analysis has been between 2 and 8 months of the year 2020. The metrics used for evaluating the health impacts of COVID-19 include incidence, mortality, and fatality rates. The water insecurity metrics differed depending on the explanatory variables of interest. Ahmad et al. (2020) evaluated poor housing conditions, and they included the following metrics: incomplete plumbing facilities, incomplete kitchen facilities, high housing cost (referring to those households that allocate 50% of monthly household income towards housing cost - including utilities-), and overcrowding. These components were evaluated together; this means that the variable on *'poor housing conditions'* included all observations that would show one or more of these conditions. Hyde (2021) evaluated water quality and she used data on water quality violation exposures by county, including: acute health-based violations (immediate health threat to exposed individuals), health-based violations involving contaminants that increase the risk of cardiovascular disease (lead, arsenic, cadmium, and copper); and all other health-based violations. These violations were evaluated separately. Silva et al. (2021) analyzed access to water and sanitation using various basic sanitation indices, including: total water service index, total sewage service index, sewage treatment index, and faecal coliforms index for tap water[19]. Amankwaa and Fischer (2020) used indicators of safe water and safe sanitation from the 'Quality of Governance OECD Dataset'[20].

Regarding the methods used by these authors, Ahmad et al. (2020) implemented multi-level generalized linear modeling, and they used total population of each county as a denominator to estimate relative risk with adjustment to population density. Silva et al. (2021) used spatial cluster analysis. Hyde (2021) used coarsened exact matching (CEM), in order to match treatment group counties (those counties with more recent violations -than average- among major community water systems) to a control group (similar counties on key demographic and environmental variables). Finally, Amankwaa and Fischer (2020) calculated the Pearson correlation.

[19] Last day of reference was from 2018 for these basic sanitation indices (Silva et al., 2020).
[20] The Quality of Government OECD Dataset, Teorell et al. (2018).

All these authors found a statistically significant association of the evaluated water security variables with either COVID-19 incidence, mortality, or fatality rates. Ahmad et al. (2020) found that in the adjusted model standardized by county population, with 5% increase in prevalence in households with poor conditions, there was 50% higher risk of COVID-19 incidence, and 42% higher risk of COVID-19 mortality. Amankwaa and Fischer (2020) found correlation between a higher case fatality rate and poorer access to safe drinking water, as well as with poorer access to safe sanitation (Pearson correlation of -0.20 and -0.30 respectively). Hyde (2021) found that on average, the case fatality rate was approximately 18% higher (0.48 percentage points; $p < 0.01$) in counties more affected by acute violations than average, and about 15% higher (0.42 percentage points; $p = 0.037$) in counties more affected by cardiovascular-associated violations. Silva et al. (2021) found that high incidence rates were significantly associated with precarious water service index and with off-standard faecal coliforms index for tap water. They also found significant association between high mortality rates and low sewage collection.

As mentioned earlier, causality has not been evaluated in any of these studies. This is precisely because of the lack of an identification strategy that would be able to isolate the effect of the variables of access to water and/or sanitation. Nevertheless, some of these studies have adjusted their analysis for some key variables, including: population density, population over 65 years of age, income, education, gender, ethnicity, age, prevalence of medical comorbidities, respiratory exposure and county-level measures air pollution, access to healthcare insurance and emergency rooms, state-level COVID-19 test density, poverty rate, average household size, occupation shares (to take into consideration differences in occupations for which social distancing is difficult).

Table 3.1: Summary of Studies on Access to Water/Sanitation and COVID-19 Incidence & Mortality

Authors, Year & Publication Status	Location of Study	Relation Evaluated	Unit of analysis & Timeframe	Health-related Metric	Water insecurity Metric	Method	Result	Other Variables
Ahmad et al., 2021 [Published at PLOS One]	USA	Association of household conditions to Covid-19 mortality and incidence rates	**Unit**: county-level (3,135 counties) **Timeframe**: through 04/21/2020	- COVID-19 mortality rate ratios and incidence rate ratios	Percenge of households in counties with poor housing conditions: - Incomplete plumbing facilities - Incomplete kitchen facilities - High housing cost (50% of monthly household income allocated towards housing cost (including utilities) - Overcrowding	Multi-level generalized linear modeling (with total population of each county as a denominator to estimate relative risk with adjustment to population density)	In the adjusted model standardized by county population, with 5% increase in prevalence in households with poor conditions, there was 50% higher risk of Covid-19 indicence, and 42% higher risk of Covid-19 mortality.	* Population density * Demographics: income, education, ethnicity, age * Prevalence of medical comorbidities * Respiratory exposure * Access to healthcare insurance and emergency rooms * State-level Covid-19 test density
Amankwaa and Fischer, 2020 [Working Paper]	Sub-Saharan Africa	Correlation between Covid-19 fatalities and poor WASH (Water, Sanitation and Hygiene) services)	**Unit**: country level (Sub-Saharan African countries) **Timeframe**: through 05/20/2020	- COVID-19 fatality rates	Indicators on safe water and safe sanitation.	Only correlation analysis implemented	Correlation between a higher case fatality rate and poorer access to safe drinking water as well as with poorer access to safe sanitation [Pearson correlation of -0.20 and -0.30, respectively].	n.r.
Hyde, 2021 [Working Paper]	USA	Association of risk of exposure to drinking water contaminants and Covid-19 case fatality rate	**Unit**: county level (2,776 counties) **Timeframe**: 01/22/2020 - 09/08/2020	- COVID-19 fatality rates	Water quality violation exposure (the sum of the estimated % of population affected by each respective violation: - Acute health-based violations, (immediate health threat to exposed individuals); - Health-based violations involving contaminants that increase the risk of cardiovascular disease (lead, arsenic, cadmium, and copper); and - All health-based violations	Coarsened exact matching. Counties with more recent violations among major community water systems than average ("treated") are matched to "control" counties on key demographic and environmental variables.	On average, case fatality rate was about 18% higher (0.48 percentage points; $p < 0.01$) in counties more affected by acute violations than average, and about 15% higher (0.42 percentage points; $p = 0.037$) in counties more affected by cardiovascular-associated violations.	* Sex and race/ethnicity composition, * Poverty rate * Percentage of the population over 65 years of age * Average household size * Reliance on public transportation * Educational attainment * Occupation shares * County-level measures air pollution * Population density
Silva et al., 2020 [Published at Transactions of the Royal Society of Tropical Medicine and Hygiene]	Brazil	Association of sanitation and Covid-19 incidence rates	**Unit**: municipality level (5,570 municipalities) **Timeframe**: 02/28/2020 - 05/31/2020	- COVID-19 mortality rate and incidence rates	Basic sanitation indices: - Total water service index - Total sewage service index - Sewage treatment index faecal coliforms index for tap water (Last day of reference for these data from 2018)	Analysis of Spatial distribution (spatial cluster analysis)	- High incidence rates were significantly associated with precarious water service index and with off-standard faecal coliforms index for tap water. -Significant association between high mortality rates and low sewage collection.	n.r.

n.r.: no reported

3.4 Evaluations on Causality Between Access to Water/Sanitation and Health Impacts

A few studies in the literature of water security and health have been able to develop a strategy to evaluate a causal relation. It is worth looking at these studies, as they exemplify type of data and methodologies that attempt isolating the impact of piped water access on health variables. I summarize the reviewed studies in Table 3.2, and I describe and discuss them in the next paragraphs.

Merrick (1985) evaluated the effect of access to piped water on early childhood mortality in urban Brazil, in the 1970s. Gamper-Rabindran, Khan, and Timmins (2010) evaluated the impact of access to piped water provision on infant mortality rate (children under 1 year old) in Brazil for the period 1970-2000. Klasen et al. (2012) analyzed the impact of extending access to piped water on population's health in Urban Yemen with 2009 data. Díaz and Andrade (2015) examined the impact of water and sanitation on child health in Peru during the period of 1986-2010.

Other studies have indirectly evaluated the impact of access to piped water (or safe water), by analyzing the privatization of water supply or the access to water from communal water suppliers. In these cases, authors have made the case on how privatization has increased piped water access, or how communal water supply has provided access to safe water in the studied locations. Galiani, Gertler, and Schargrodsky (2005) evaluated the impact of privatization of water services on child mortality in Argentina during the period 1990 -1999. Kosec (2014) analyzed the impact of water supply privatization on child health, with data from 39 African countries for a time span of 1986-2010. Ziegelhöfer (2012) examined the effect of communal water supply on health and diarrhea in rural Guinea between 2003 and 2005. Calzada and Iranzo (2021) evaluated the impact of community organizations (Juntas Administrativas de Servicios de Saneamiento) on two water related child health outcomes: diarrhea and low birth weight, in Peru and for the period 2010-2014.

Dearden et al. (2017) evaluated the association of water source and sanitation type to child growth. This is the only study that I have included in Table 3.2 that evaluates association and not causality, I have included this study because it is a careful long-term study. These authors relied on survey data from children that were enrolled in 2002 at 6–17 months, and followed them in 2006–2007 at 4–5years, and 2009–2010 at 7–8years. The authors explained that they could not evaluate causality as they lacked key information on birth length, measures of child hygiene, and actual use of improved water and toilets.

Methods

Regarding the methods used in these studies, authors relied on quasi-experimental methods, structural equations, or instrumental variables. As observed in Table 3.2, it is not common to find randomized experiments in this literature, and neither is common to find good instruments of policies on access to improved water and sanitation. At the same time, the provision of piped water is often highly correlated with other observable and unobservable socio-economic determinants of the population and institutional factors, which lead to biases.

Merrick (1985) used three structural equations: husband earnings[21], household's access to piped water, and child mortality, and applied OLS. In order to estimate with OLS, they verified two restrictions: first, that the model of the three equations was fully recursive (as opposed to a simultaneous relationship), this means that the husband's earnings was causally prior to the households' access to piped water, and both were causally prior to child mortality. The second restriction was that error terms of the three estimating equations would be uncorrelated with each other and with the right-hand side variables. Then, they used OLS estimates of the reduced form coefficients of the exogenous variables to estimate their effect on child mortality, as well as path analytical techniques to decompose their total effect into direct effects on child mortality and indirect effects through endogenous variables of income (husband earnings) and household's access to piped water.

When using panel data, the identification strategy has been generally based on statistical approaches that use mean regression and exploit panel variation, and estimate fixed effects to control for time-invariant sources of correlated errors. The study of Díaz and Andrade (2015) in Peru used this method with district fixed effects. In these cases, the main threat to identification is the existence of time-varying, unobserved covariates correlated with the policy to access water or sanitation and child health. Galiani, Gertler, and Schargrodsky (2005) used a difference in difference approach, and in order to take into consideration some part of the time variation, they allowed for an arbitrary covariance structure within municipalities over time, by computing standard errors clustered at the municipality level. Also, they computed standard errors clustered at the province-year level.

Also, Gamper-Rabindran, Khan, and Timmins (2010) exploited panel variation and estimate fixed effects at various quantiles of the conditional infant mortality rate distribution (effect of the treatment on various quantiles of the outcome distribution, making no assumption about the joint distribution of the treated and untreated distributions). Kosec (2014) used an instrumental variables strategy. She constructed an instrument, which was the former non-African colonizer's share of the world market for private, piped water (ignoring contracts covering African countries). She explains that with this instrument she assumes that African countries are relatively more likely to undergo privatization in the water sector during years when their former (non-African) colonizer's world water market share is relatively high. Klasen et al. (2012) identifies some potential instrumental variables given that the policy decisions on construction of water and sanitation infrastructure were based on policy decisions that could be exogenous to the outcome variables in the study. Therefore, they used some suitable instruments, including: distance to the city centre of each household, the age of the house, and existence of rocky ground around the dwelling[22].

On the other hand, when using only cross-sectional data, studies have used propensity score matching and difference in difference estimation (e.g. Klasen et al. 2012).

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21 Husband's earnings were used as a proxy for household income because the study population "consist[ed] of mothers, with husbands present, in single family households, and only a small proportion (.08) of those women were working."

22 The authors explain that the construction of water and sanitation schemes followed three principles: "First, construction always began in the city center. Second, the Old City was prioritized, where buildings are substantially older. Third, in the mountain region pipe construction excluded streets built on particularly hard rock due to increased construction cost."

Other authors have used quasi-experimental models, in particular Regression Discontinuity (RD) design. These authors have found a clear instrument that impact the policy of access to water or sanitation, which is exogenous to the demand of the water/sanitation service. The studies in this review that use this method are Calzada and Iranzo (2021) and Ziegelhöfer (2012). Calzada and Iranzo (2021) used the arbitrary cut-off of 2,000 inhabitants (classification between district urban or rural subunits), as instrument. Using this cut-off as instrument was possible because in the 2000s the Peruvian legislation established a markedly different provision of water within districts: rural population units were encouraged to be supplied by communal provision, whereas urban population units were to be served by public provision. Ziegelhöfer (2012) used a fuzzy RD design, in which the defined instrument was a government policy that villages characterized by investment cost of less than 100 Euro per inhabitant were eligible to receive the rural water supply program. (The specific investment costs depended on the costs of the drill -i.e. geological characteristics- of the area).

Results

Various of the studies reported a statistically significant effects of piped-water (or safe water) access on the health variable(s) of interest and for the studied locations (Galiani, Gertler and Schargrodsky, 2005; Gamper-Rabindran, Khan and Timmins, 2010; Ziegelhöfer, 2012; Kosec, 2014; Díaz and Andrade, 2015; Calzada and Iranzo, 2021). However, some authors reported on heterogeneity of results. For example, Calzada and Iranzo (2021) reported that the sign of the estimated coefficient on communal water system differed across regions. While for the Sierra and Selva regions results were not statistically different from zero, in both diarrhea and low birth weight models, the point estimates for the Coast were positive and significant. Also, other studies found heterogeneity in the magnitude of the effect. Kosec (2014) found that children from the poorest households benefited most. Also, Gamper-Rabindran, Khan, and Timmins (2010) found that provision of piped water reduced infant mortality by significantly more at the higher conditional quantiles of the infant mortality rate distribution than at the lower conditional quantiles (except for cases of extreme underdevelopment).

Merrick (1985) found that access to piped water had a significant but secondary impact on differences in child mortality, accounting for about one-fifth of such differences; while exogenous household variables (education of mothers and husbands) had the greatest total effect on differences in child mortality and that most of this effect was direct.

Moreover, and very importantly, some authors found the opposite relation: that access to piped water worsened a specific health outcome. For example, Klasen et al. (2012) found that access to piped water supply worsened health outcomes when water rationing was frequent. Also, other authors have discussed about the importance of including behavioral variables in these models, when possible, because behavior is an important confounding factor when analyzing health outcomes. Behavioral responses could change the expected result of a water security intervention. For example, Hasan and Gerber (2016) evaluated the impact of a piped water network provided to rural households of north-western Bangladesh. They found that the project had a positive impact on access to improved water and significantly reduced the distance traveled for and time spent on collecting drinking water. However, they did not find improvement in the drinking water quality, which was measured by the extent of fecal contamination[23] at the point of use. These authors explained that the treated households owned larger water containers, which implied that the intervention had a clear impact on the quantity of water used for household purposes; however, they did not find evidence that the intervention had impact on hygiene and therefore on health benefits (such as decreased diarrhea incidence of in under-five children, improved child stunting, and underweight of children) due to piped water use.

Control variables

Several variables are commonly used as controls, including demographic and socio-economic characteristics, behavioral and health related information, community/regional characteristics, and geographical characteristics. These variables were constructed with household survey data, surveys directly to mothers, census data, or county/district/country data. Below, I summarize the variables used in the overall reviewed studies[24]:

- Demographic characteristics of household members, including: household size, number of children, number of household members per room/house, age, gender,
- Socio-economic variables, including: household income or wealth (e.g. household assets), education level of parents, household migration status,
- Behavior is very important in these studies. Those studies that use survey data use variables on behavior that could be related to health, some of them include:
  - Hand washing
  - Soap use
  - Water purification (though boiling, chlorination, or use of water filter)
  - Knowledge about water-related diseases
  - Other hygiene practices

- Health related variables, including:
  - Whether the child is breast feeding or not
  - Information on vaccines

- House infrastructure variables, including: type of toilet facilities, whether household members share toilets with other dwellings, materials in floors, materials in walls, experience problems with water supply, water quality, household's assets, household has electricity.

- Characteristics by district (municipality/community/region/county), including, hospital presence, secondary school presence, population, and community wealth, political affiliation of the local government, local government's public spending per capita, GDP per capita, income inequality, unemployment rate, percentage households with sewage connections (to account for improved sanitation), aid per capita, foreign direct investment per capita, per capita value added tax.

- Geographical variables include, region, altitude.

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[23] E. coli count per 100 ml of water.
[24] Table 3.2 indicates the variables used in each study.

Table 3.2: Summary of Studies on Access to Water/Sanitation and Health that Evaluate Causality

Authors & Year	Location	Impact Evaluated	Unit of analysis & Timeframe	Health-related Metric	Water insecurity Metric	Method	Result	Other Variables
Calzada and Iranzo, 2021	Peru	Impact of community organizations on two water related child health outcomes: diarrhea and low birth weigth.	**Unit**: child and household (pooled cross-section of over 84,600 households and about 26,200 children under five) **Timeframe**: 2010 - 2014	* Diarrhea: dummy that takes value 1 if the child experienced diarrhea in the two weeks prior to the interview, and 0 otherwise. * Low birth weight: dummy variable with value of 1 if the child's weight at birth is less than 2.5 kg.	Having water provision from the communal system	Regression discontinuity design. (Instrumented with a binary variable that takes 1 if the distrit sub-unit where the household resides has less than 2000 inhabitants (cut-off)).	Diarrhea and low birth weight were significantly lower for households served by community organizations in the Coast Region. Note: the sign and statistical significance of the estimated coefficient on communal water system differed across regions.	- Type of toilet, sharing toilet - # household members per room, # children in the household, age, gender - Mother's age, education and ethnicity - Household income index and assets - Whether the household boils the water - Mother's hand washing, hand washing for preparing food & feeding the child - Whether the child is breast feeding or not - Vaccines pneumococcal and rotavirus - Geographical region, altitude - District population
Dearden et al., 2017	India Peru Ethiopia Vietnam	Associations between water sources, sanitation type, and child growth. **(no causality evaluated in this study)**	**Unit**: child (8,062 children) **Timeframe**: children were enrolled in 2002 at 6–17 months, and followed in 2006–2007 at 4–5years, and 2009–2010 at 7–8years.	* Stunting (height-for-age) * Thinness Length (at 1y) and height (at 5y and 8y) (Height-for age z-scores and body mass z-scores calculated using WHO 2006 standards)	Measures of households' main source of water and sanitation: * Water source classified as: borehole, tube well, piped water, public standpipe, community water tank, rain water, and other. * Toilets type classified as household flush toilet, piped sewer system connection, septic system connection, composting toilet, and pit latrine.	Estimated risk ratios with poisson regression and OLS regression with community clustered errors.	Stunting at 1 year was less common among children with good toilet access than among those without access and this difference persisted when children were 5 years and 8 years.	- Child's sex and age - Asset index in concurrent round - Mother's height, age, completed schooling grades - - Father's completed schooling grades - Household migration between rounds and urban/rural residence - Community characteristics, including: hospital presence, secondary school presence, population, and community wealth
Diaz and Andrade, 2015	Peru	Impact of water and sanitation on child health.	**Unit**: District **Timeframe**: 1986 - 2010	* Prevalence of diarrhoea * Anthropometric indicators of nutritional status: weight-for-age, height-for-age and weight-for-height z scores * Indicators of malnutrition: stunting, wasting, and underweight.	* Household's access to piped water from the public network as opposed to water from wells and public taps or other sources. * Household's access to sanitary facilities connected to the sewage system as opposed to latrines and pit toilets and other types of sanitation (including defecation in open spaces).	District fixed-effects model	Access to piped water for drinking and flush toilets or latrines reduced the prevalence of diarrhea.	- Household head education - Crowding index - Materials in floors - Materials in walls - Sanitazing practices (boil/chlorinate water)

Table 3.2: Summary of Studies on Access to Water/Sanitation and Health that Evaluate Causality (Continuation)

Authors & Year	Location	Impact Evaluated	Unit of analysis & Timeframe	Health-related Metric	Water insecurity Metric	Method	Result	Other Variables
Galiani et al., 2005	Argentina	Impact of the privatization of water services on child mortality.	**Unit**: Municipality level **Timeframe**: 1990 - 1999	* Child mortality rate constructed (Ratio of the number of deaths of children less than 5 years old to the total number of children less than 5 alive at the beginning of the year).	* Type of water service provision (water provider is publicly owned or privately owned)	Difference in difference approach (allow for an arbitrary covariance structure within municipalities over time by computing standard errors clustered at the municipality level. Also, compute standard errors clustered at the province-year level.)	Child mortality fell 8 percent in the areas that privatized their water services and that the effect was largest (26 percent) in the poorest areas.	Municipalities characteristics: - Socio-economic stratum of municipalities - Public spending per capita - Political party of local government - GDP per capita - Unemployment rate - Income Inequality - Household head's age
Gamper-Rabindran et al., 2010	Brazil	Impact of piped water on under-1yr infant mortality rate.	**Unit**: county 3,568 counties (or minimally cmparable areas from Institue for Economic Analyisis) **Timeframe**: 1970-2000	* Infant mortality rate (deaths per 1000 live births)	Percentage households with piped water	Quantile treatment effects with panel data (weighted by county population)	Provision of piped water reduced infant mortality by significantly more at the higher conditional quantiles of the infant mortality rate distribution than at the lower conditional quantiles (except for cases of extreme underdevelopment).	County characteristics: - Percentage households with sewage connections - Human Development Index - Education - Total fertility rate - Population - Income
Klasen et al., 2012	Urban Yemen	Health impact of extending access to piped water.	**Unit**: Household (2,518 randomly selected households). **Timeframe**: 2009	* Health variables on Diarrhea and Severity (Constructed from household interviews that collected information on symptoms rather than diseases, microbiological water test results and secondary data from schools and health facilities).	Access to piped water and sanitation.	Difference in difference with propensity score matching Instrumental variable regression	Access to piped water supply worsened health outcomes when water rationing was frequent. Connections to piped sewers could lead to health improvements, conditional on regular water supply.	- Hygienic practices: hand washing, soap use, water purification (e.g. use of water filters, chlorination and boiling) - Education - Knowledge about water-related diseases - Problems with water supply - Water quality - Sewerage system - Demographic structure of the household - Water test data

Table 3.2: Summary of Studies on Access to Water/Sanitation and Health that Evaluate Causality (Continuation)

Authors & Year	Location	Impact Evaluated	Unit of analysis & Timeframe	Health-related Metric	Water insecurity Metric	Method	Result	Other Variables
Kosec, 2014	39 African countries	Impact of water supply privatization on child health.	**Unit**: child **Timeframe**: 1986 - 2010	* Dummy for whether a child experienced diarrhea at some point during the last two weeks (a child is indexted by subnational region or residence, month and year that he is surveyed).	* Dummy for private sector participation in the water sector in the subnational region and year of survyed child.	Panel data fixed-effects and IV strategy (IV constructed: former colonizer's time-varying share of the world market for private, piped water -ignoring contracts covering African countries-).	Privatization of the water supply decreased diarrhea among urban-dwelling, under-five children by 2.6 percentage points, or 16% of its mean prevalence. Children from the poorest households benefit most. Privatization of the water supply was also associated with a 7.8 percentage point increase in school attendance of 7–17 year olds.	- Mother has primary education - Secondary or mor education - Household has electrity - Household assets (ratio, television, refrigerator, bicycle, motorcyclce, car, ntural floor) Country's characteristics: - World Bank water grants/loans per capita - Net United Nations aid per capita - Foreign direct investment per capita
Merrik, 1985	Brazil	Effect of piped water on early childhood mortality.	**Unit**: women (sample from 1970 census and 1976 survey) **Timeframe**: 1970 and 1976	* Infant mortality rate (Actual proportion of children surviving for women in the study population to the proportion that would be expected to survive given a standard mortality schedule). Standarization: used a method by Trussed and Preston (1982) for standardizing survival ratios in individual level data.	Dummy variable indicates whether the household in which the mother resided had access to piped water at the time of the interview.	Structural equations: husband earnings , household's access to piped water, and child mortality, and applied OLS and path techniques to estimate the direct and indirect effects of explanatory variables.	Access to piped water had a significant but secondary impact on differences in child mortality, ac- counting for about one-fifth of such differences. Exogenous household variables (education of mothers and husbands) had the greatest total effect on differ- ences in child mortality.	- Husband's earnings - Husband's education - Mother's education State characteristics: - Per capita value added tax - Ratio of households in region with piped water to total households in region
Ziegelhöfer, 2012	Rural Guinea	Effect of communal water supply with health and diarrhea.	**Unit**: household (1,770 households in 105 rural villages) **Timeframe**: 2003 and 2005	* Diarrhea prevalence among children until five years of age (Used survey information on whether at least one child in the household experienced an episode of diarrhea in the previous two weeks. A diarrhea rate within the households and an overall prevalence rate were calculated).	Dummy variable indicating in the water supply program was implemented in that village.	Fuzzy Regression Discontinuity design. (Instrument: policy that villages that had investment cost of less than 100 Euro per inhabitant were eligible to receive the rural water supply program. Costs depend on the costs of the drill -i.e. geological characteristics-).	Significant reduction in the prevalence of diarrhea due to the communal water supply program.	- House owenership - Mother living alona or with husband - Matrial status - Education - Household size - Economic activity

4 Conclusion

The majority of studies on the relation of human health impacts to housing conditions and water security components (e.g. water access, water quality, type of sanitation) analyze association, and only few analyze causality. This is due to the difficulty of finding an identification strategy and the empirical complexities of isolating the impact of water security components from other contextual factors. Nevertheless, there are some exemplary studies that have used innovative and careful methods and data to analyze causality. Future studies on similar topics could refer to these examples for evaluating the type of data and variables, estimation options, and research design.

To this date, most studies on the relation between COVID-19 health impacts and water security, energy security, and more generally housing conditions and socio-economic characteristics, have been implemented with aggregate data (county, district, municipality levels). Studies with micro-data will be valuable, as they will be able to provide further evidence. Special attention should be paid to the incorporation of behavioral variables (habits, knowledge, attitudes on health and hygiene), as they can be key confounders. These data are mainly obtained at micro-level through surveys.

Finally, the literature on the relation of socioeconomic characteristics and housing conditions to health has also reported that sociodemographic factors may contribute to disparities in the impact of health-related issues. Careful and robust methods should be applied to account for these factors, in order to isolate the impact of the explanatory variable(s) of interest.

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