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Abstract

This survey sheds light on the causes and consequences of the global sanitary revolution that resulted in the spread of waterworks and sewerage projects since the middle of the 19th century, by drawing on research from the fields of economic history, economics and history. I begin with a discussion of the construction of these infrastructures during the period 1850-1940 showing that their spread was relatively similar in major urban cities across the globe, while diffusion within countries and cities themselves was markedly unequal. Second, I review research looking at the mortality impact of access to clean water and sanitation. These account for ca. 10-30 percent of declines in infant mortality and in industrial settings their joint effect explains between 20 and 25 percent of the fall in infant and overall mortality. Lastly, I examine the drivers of the sanitary revolution with a new framework that distinguishes between proximate factors (e.g. physical capital) and ultimate factors (e.g. institutions). I argue that the state of knowledge in this literature is insufficient to explain between- and within-country differences in access to sanitary services and that more attention should be devoted to the interaction of political factors with economic, cultural and biogeographic contexts.

JEL Codes: I18, N30, N90, L95

Keywords: waterworks, sanitation, mortality, political economy, cities

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1. Introduction

Ensuring good health for all and universal access to sanitary services are key priorities of the international development agenda, as highlighted by the Sustainable Development Goal number 3 and 6 (United Nations, 2022). This is not surprising given the terrible health prospects of millions of people in low-income regions as a result of, in part, poor access to efficient systems of safe water supply and sewage disposal. Low rates of handwashing, open defecation and in-house and source water contamination (among others) foster the transmission of fecal-oral diseases, such as diarrhea, which take a high toll on the population by impairing children's physical and cognitive development and, in the worst cases, lead to preventable deaths.

The unequal provision of modern water and sanitation services, except for a few exceptions, are not entirely due to recent phenomena. Rather, they are the outcome of a long process of unequal economic development and public health interventions that can be traced back, at least, to the mid-19th century, when large-scale waterworks and sewerage systems diffused widely. The aim of this article is to examine the causes and consequences of this 'sanitary revolution' between ca. 1850-1940 by surveying the historical literature. I consider studies primarily published in the field of economic history, although I also draw extensively on research from economics, history and historical demography. The analyzed period holds particular relevance because, as I will demonstrate, it marks the starting point of diverging trends between different parts of the world. These trends, in some instances, continue to shape present-day inequalities in access to sanitary services.

This survey contributes to earlier overviews of the field in four ways. First, I provide a rough sketch of the global (urban) diffusion of waterworks and sewerage systems, using a mix of published datasets and newly gathered information since the mid-19th century for different world regions. I place special emphasis on the period 1850-1940, although I will also discuss briefly certain trends in lower-income countries after 1950. This exercise identifies distinct between- and within-country patterns that will bring about some (unanswered) questions worth pursuing from an international and comparative perspective that the literature has missed so far. Second, I review the (econometric) research looking at the effect of clean water and waste disposal interventions on mortality and offer a reasonable ballpark of their average impact. This adds to previous authoritative pieces on the determinants of mortality (e.g. Costa, 2015; Cutler, Deaton, & Lleras-Muney, 2006; Floud, Fogel, Harris, & Hong, 2011), by putting together and assessing a substantial amount of evidence that has emerged in the last five years. Third, I propose a new framework, to the best of my knowledge, to study the determinants of spending on waterworks and sewerage that distinguishes between *proximate* and *ultimate* factors à la growth economics. The former refer to observable factors or inputs of a production process that are

required to offer sanitary services, such as physical and human capital; ultimate factors, on the other hand, are processes that operate indirectly and over a longer time frame, such as institutions, biogeography or culture. This distinction, I argue, allows us to better understand between- and within-country diffusion patterns of these large-scale infrastructures because it isolates slow- and fast-moving mechanisms that influence their supply and demand. Finally, this survey not only draws on evidence from the United States and Europe that has recently been summarized by other authors (e.g. Beach, 2022; Bogart, 2022; Clay, 2023), but also uses an array of experiences from countries that typically receive less attention. This creates a more solid knowledge basis to assess the generalization of certain findings from the literature and, perhaps more importantly for the main purpose of this piece, it portrays a fuller and more accurate representation of the state of the knowledge frontier in economic history and adjacent fields.

The remainder of this article is structured as follows. I discuss the beginnings of modern waterworks and sewerage in Western Europe and then I present evidence of their worldwide diffusion between ca. 1850 and 1940. The next section turns to their consequences on the health of the population and after that I introduce a new framework to analyze their causes. Lastly, I conclude emphasizing a few areas for future research with potential to improve our knowledge of the long-run causes and consequences of water and sanitation investments.

2. The beginnings of modern waterworks and sewerage

The origins of modern waterworks and sewerage can be traced back to the 19th century, when three major developments created a favorable environment for these systems to evolve and spread: changing perspectives on public health, increasing demand for water and sanitation and technological change. The first development relates to a fundamental transition in the realm of ideas concerning the health of individuals and its relation with factors beyond their control. Already in the 18th century, the Enlightenment had paved the way for the notion that social improvement could be achieved with environmental reform. Collecting data became important in order to replace popular beliefs about disease causation with empirical facts that could be subsequently tested. An example of this approach was the work of Louis René Villermé, a French physician that became interested in social epidemiology, who thought that statistical data could be used to grasp the condition of the population, with a special emphasis on the poor. He produced a seminal study in 1828, among others, examining mortality differentials between rich and poor districts in Paris, and correlated these to various explanatory variables (Coleman, 1982). Similarly, the study of how individual health might be affected by societal factors also flourished in English circles. Edwin Chadwick published his work on the sanitary condition of English workers in 1842, which shifted the focus of disease causation away from individuals. One of

his recommendations was that cities built an integrated system of pipes and sewers that could bring large amounts of water and efficiently dispose them along with waste (Chadwick, 1842). This landmark study gave local governments a framework to understand local infrastructural needs and how these could be met, which eventually removed fatalism and increased agency to implement effective strategies (Melosi, 2000, pp. 71-70). This marked a significant milestone, primarily because (typically) the local policy realm was crucial in turning novel ideas about disease prevention into tangible sanitary infrastructures. It was at this level that relevant decisions and debates occurred, determining who would pay for their construction (taxpayers versus private consumers) and who would have access to pipes and sewers. At the national level, the growing recognition of environmental factors raised awareness in a number of countries that gradually committed to promote public health during the 19th century via, for instance, state regulation and funding (Porter, 1999, pp. 101-105; G. Rosen, 1958/1993, p. 196). To be sure, these developments should not be overstated because sanitarians and medical experts were more often than not wrong and their theories were met with skepticism both within and outside their field. It took a long time to get the epidemiology of many diseases right, but it is undeniable that a fundamental shift in thinking about disease took place during the 19th century, which was further reinforced with the development of bacteriology after the 1880s (Mokyr & Stein, 1996).[1] Communities felt that they were in charge of their health condition and, in this narrative, the civil engineer was the physician that could cure the ills of the city.

The second factor that propelled the age of sanitation is closely tied to its demand. Increasing urbanization, population and industrialization exerted mounting pressure on traditional systems, rendering them obsolete due to their limited capacity. In addition, the contamination of water sources and close contact with human waste made them hazardous. Drinking water in urban areas was of poor quality and waste management highly insufficient, which was often linked with deadly epidemics, such as cholera.[2] Also, fear of uncontrolled fires and their associated losses created additional incentives to establish sources of abundant water throughout cities, such as hydrants. These risks were recognized by the fire insurance industry in the United States by assigning higher rates to towns without waterworks (L. Anderson, 1984, p. 217). To remedy problems of scarcity, large-scale centralized

[1] An example of the resistance towards new and more accurate ideas about disease causation, and their eventual triumph, is the tragic story of Max von Pettenkoffer. He was once an internationally-renowned public health expert who played a significant role in promoting sanitation in Germany. However, his mistaken ideas regarding the ineffectiveness of water filtration were discredited after the 1892 cholera outbreak in Hamburg. The scientific paradigm of bacteriologists, such as Robert Koch, prevailed and Pettenkofer's reputation greatly suffered. In 1901, depressed, he committed suicide (Morabia, 2007).

[2] As I will discuss later, demand concerns were initially voiced by elites and industrial users who gained access to the sanitary networks first. These privileged groups not only possessed greater purchasing power to pay for these services, but also contributed more in taxes and controlled investment decisions by local councils, especially when such infrastructures were publicly owned.

infrastructures provided an efficient technical solution that connected individual households with pipe and sewer networks capable of transporting unprecedented levels of water and waste throughout the city in a controlled manner. As a result, urban sewage disposal and water consumption grew inexorably during the late 19th century. Citizens in Boston and Chicago, for instance, went from consuming about 100 gallons per capita daily in 1880 to 150 and 200 gallons in 1905, respectively (Melosi, 2000, p. 130).

The third factor enabling the sanitary revolution was technological change. Although centralized water supply and sewerage systems were available before the 19th century, their capacity was rather low by modern standards. Also, the complexity and cost of these pre-industrial infrastructures were significant and most places relied on traditional methods to collect water and get rid of waste, such as wells, rivers, lakes or canals. This began to change in the 19th century as various technological innovations brought quantitative and qualitative improvements. Regarding water provision, the adoption of steam engines for pumping purposes allowed for the distribution of large amounts of water through pipe networks made of iron and lead, instead of wood, that could handle increasing levels of water pressure. While waterworks proved to be beneficial in the long term, their potential harm became apparent when the supplied water was not filtered. A classic example is the city of Hamburg, which suffered a terrible cholera epidemic in 1892 when waterworks supplied contaminated water to its citizens. Conversely, a neighboring city, Altona, sourced its water from the same river but managed to avoid the outbreak thanks to a filtration system (Evans, 1987).[3] Unfortunately, filtered water was not widely provided because its benefits were not properly understood until the late 19th century when germs became the focus of public health efforts. A more reliable and safer procedure would come at the turn of the 20th century with the application of chemical water purification using chlorine (Melosi, 2000, pp. 143-145). Another limitation of early waterworks relates to their challenges in providing uninterrupted service, often operating for a few hours daily or on alternate days. London, a frontrunner in water provision, struggled with this almost 80 years before constant and reliable supply was present in most homes (Hardy, 1991).

As for waste management, the availability of abundant water was employed to dispose of solid and liquid waste through sewers, which were increasingly covered to minimize contamination. Sewer access replaced a number of unsafe methods to store fecal matter (e.g. cesspits, privies, pail closets) with water toilets. As with waterworks, these technologies did not always lead to immediate improvements in health outcomes because sewers often discharged waste into rivers or in the sea, where tidal waves would bring it back. Uncertainties about this technology made some cautious, such as the Prussian government, which prohibited the pouring of untreated sewage into rivers (Hennock,

[3] Similarly, Tampere suffered a typhoid epidemic in 1916 as a result of the distribution of contaminated water (Peltola, Saaritsa, & Mikkola, 2024).

2000, p. 281). Eventually, waste management gradually improved after the introduction of sewage treatment techniques, such as the irrigation of cultivated land, intermittent filtration or biological and chemical procedures that disinfected sewage and removed solids (Melosi, 2000, pp. 167-170).

These three factors – changing ideas about health, rising demand and technological change – happened at different times during the 19th century and jointly paved the way for the sanitary revolution. The pace of this process greatly differed across time and space creating within- and between-country differentials in access, which I discuss in the next section.

3. The global diffusion of waterworks and sewerage

Industrialization and technological change were key in the emergence of modern water and sanitation infrastructures, so it is no surprise that their 19th-century origins have British roots. This process can be observed in the major infrastructural investments that represented a growing share of the national capital stock and the destination of loans sanctioned by central government departments (Harris & Hinde, 2019, p. 348; Millward, 2000, p. 317).

We lack a comparative database on the diffusion of sanitary infrastructures worldwide. However, various pieces of scattered evidence indicate that they were established in a number of major cities beyond the United Kingdom from the mid-19th century onwards. For instance, consider some waterworks construction dates in Europe, e.g. Hamburg (1849), Madrid (1858) or Helsinki (1876); in the Americas, e.g. Bogotá (1888), Buenos Aires (1869) or New York (1842); in Asia, e.g. Bombay (1858) and Yokohama (1887); and in Africa, e.g. Saint-Louis (1886).[4] Modern sewerage systems were built around the same time, albeit with a delay that differed across places as illustrated by the cities of Madrid (1865), Helsinki (1880), Buenos Aires (1905), Calcutta (1875) and Durban (1896); there were exceptions to the rule, such as Hamburg (1842) and parts of Massachusetts that installed sewerage systems before waterworks.[5] While future research should examine this in a more systematic manner adding more municipalities, the pattern of global diffusion seems quite robust. This was due to, in part, rising challenges in the realm of public health and firefighting, the international exchange of scientific knowledge and the work of European engineers beyond the old continent (see section 5).

The process of diffusion accelerated in some countries in the 1870s, which created long-lasting diverging trends between industrialized and non-industrialized countries. Again, the lack of

[4] For Europe, see Grahn (1904, p. 303), Peltola and Saaritsa (2019, p. 306) and March (2015, p. 357); for the Americas see Felacio Jimenez (2017, p. 43), Juuti, Katko, and Vuorinen (2007, pp. 433-434) and Melosi (2000, p. 83); for Asia see Broich (2007, pp. 354-356); for French Africa see Ngalamulume (2007, p. 157).

[5] The sources are Pinto Crespo, Gili Ruiz, and Velasco Medina (2015, p. 211), Peltola and Saaritsa (2019, p. 306), Muñoz (2019, p. 107), Goode (1916, p. 119), Mäki (2010, p. 100), Gallardo-Albarrán (2020, p. 736) and Alsan and Goldin (2019, p. 622).

standardized data makes it difficult to show this thoroughly but, to partially overcome this problem, I have put together information on the timing of waterworks and sewerage systems from various secondary sources that cover the early (urban) diffusion phase in a few countries between 1870 and 1940. The small sample considered here includes the frontrunner in sanitary matters at the time (United Kingdom) along with a number of industrializing followers (United States, Germany and the Netherlands) and a country from the 'Global South' (Colombia). Table 1 presents the absolute number of waterworks and sewerage systems, and the percentage of towns over ten or fifteen thousand inhabitants with these infrastructures at different points in time. The latter allows for spatial and temporal comparisons of countries with different population size, although two caveats are necessary. First, the coded dates do not imply that all citizens in a given city had access to piped water or that traditional methods (e.g. public fountains, wells, cesspits, privies) were immediately discarded. Instead, the coverage rates in table 1 convey information on the extent to which a given urban system had some type of access to modern water and sanitation. Unfortunately, the sources do not indicate which type of technology was in place (filtration, chlorination, sewage treatment, etcetera). The second caveat concerns the sample, which I do not claim to be representative but rather illustrative. For this article, practical and data availability considerations have motivated the choice of countries.

Panel A of table 1 presents a number of interesting patterns that partly reflect some of the origins of current inequalities in access to safe water. First, the United Kingdom was the indisputable leader: almost all British towns had waterworks around 1880, while the United States and Germany lagged behind with coverage rates around 80 and 40 percent, respectively. Second, substantial investments were made from the 1870s onwards, although the pace of progress was uneven between countries. In the group of industrializing economies, we see that Germany and the Netherlands lag behind the United States by one and two decades, respectively. This delay is greater if we take the United Kingdom as the benchmark for comparison, although it is much shorter than that experienced in Colombia where only 61 percent of municipalities with more than 15,000 people had waterworks by 1938,[6] after decades of meager investments in many parts of the country. This coverage had been achieved about half a century (or more) earlier in Europe.

[6] This number refers to municipalities where more than five percent of buildings had piped water; a 1-percent cutoff increases the reported coverage in table 1 from 61 to 69 percent.

Table 1. Diffusion of waterworks in some selected countries, 1870-1940

	Panel A: Waterworks					Panel B: Sewerage systems	
	1870	1880	1890	1900	1938	1900-1910s	1938
England and Wales							
- *Number of cities*	-	212	-	-	-	250	-
- *% of towns over 10,000 in ca. 1880*	-	95%	-	-	-	95%	-
United States							
- *Number of cities*	99	160	201	-	-	145*	-
- *% of towns over 15,000 in 1890*	49%	78%	99%	-	-	71%	-
Germany							
- *Number of cities*	37	121	203	269	-	264	-
- *% of towns over 15,000 in 1900*	13%	42%	70%	92%	-	91%	-
The Netherlands							
- *Number of cities*	2	6	23	32	-	17	-
- *% of towns over 15,000 in 1899*	6%	17%	66%	91%	-	49%	-
Colombia							
- *Number of cities*	-	-	-	-	76	-	52
- *% of towns over 15,000 in 1938*	-	-	-	-	61%	-	42%

Sources Panel A: Hennock (2000, p. 281) for England and Wales; M. N. Baker (1891) for the United States; Kaiserliches Gesundheitsamt (1904), Grahn (1898-1902) and Grahn (1904) for Germany; Vakgroep Waterleidingbedrijven (1948) and the population census conducted in 1899 for Dutch waterworks and population, respectively; Building Census conducted in 1938 and Fuentes-Vásquez and España-Eljaiek (2022) for Colombian waterworks and population, respectively.

Sources Panel B: Local Government Board (1913, Appendix I of part 3) and Bennet (2012) for England and Wales (data refer to 1911); U.S. Bureau of Census (1913, pp. 88-99) for the United States (data refer to 1909); Kaiserliches Gesundheitsamt (1904) for Germany (data refer to 1904); Vereeniging voor waterledingsbelangen in Nederland (1917) for the Netherlands (data refer to 1915); Building Census conducted in 1938 and Fuentes-Vásquez and España-Eljaiek (2022) for Colombian waterworks and population, respectively. The data refer to the systematic disposal of waste via sewers and, in some cases, water toilets. * The figure for the United States is likely an underestimation since the source reports cities over 30,000 people in 1909.

Information for sewerage systems and water closet coverage is much scarcer, but some available sources allow a meaningful comparison across industrialized countries in the 1900s-1910s. Panel B of table 1 shows that the systematic disposal of urban waste using sewerage and water closets was extensively implemented in urban England and Germany, while the Netherlands and the United States lagged behind. In Colombia, the level of infrastructural investment was much lower: only 42 percent of towns over 15,000 inhabitants had some access to modern sewerage. Although we cannot pinpoint exactly when the gap between industrialized countries and Colombia, and probably other low-income countries, started widening, table 1 suggests that this must have happened before 1900. In sum, significant differences can be observed in the urban diffusion of water and sanitation projects both within and between countries before ca. 1880; after that only some (industrialized) countries

converged. To some extent, these diverging experiences reflect differential access to financial markets, engineering knowledge networks and biogeographic endowments (more on this below).

Until now, I have focused on the extensive margin of centralized water provision and waste disposal as measured by whether a municipality had these infrastructures, which admittedly says little about actual access to pipes and sewers. To examine this in relation to between-city diffusion, ideally, we would continue with the sample in table 1 and examine within-city coverage rates, but such data are not available unfortunately. Instead, I draw on various secondary sources to track the spread of these networks in major cities located in some of the regions discussed earlier and a few others between 1870 and 1940. Comparisons of this sort are more difficult because data are more limited and patchy. For instance, in the case of water provision the figures reported in table 2 can refer to the percentage of buildings, households or population connected to the pipe network. This does not necessarily mean that people received tap water at home, since statistics often combine lots supplied with a standpipe, or that the service was constant throughout the day (Troesken, Tynan, & Yang, 2021). With respect to sewerage, for which data are particularly patchy, some figures refer to the percentage of toilets connected with sewers or the number of houses with sewer connections. A final caveat is that city-specific trends are not necessarily representative of the national experience, although they do convey valuable information on how other comparable municipalities may have fared in those countries. Take the case of Chicago that built waterworks in the 1840s and provided piped water to most citizens a few decades later. While this development may appear exceptional, a survey conducted in 1909 shows that more than half of American cities had coverage rates of 95 percent or higher (Troesken, 2004, p. 39). Therefore, the figures in table 2 provide meaningful insights on the origins and long-term evolution of municipal access to water in different parts of the world.

Table 2 shows that, as before, England was a clear frontrunner followed by the United States. By 1830, about 90 percent of households in London received water from one of the water companies operating in the city and a few decades later most of them had access to piped water in one way or another. In Chicago, near universal provision had been achieved ca. 1870. In other places, similar coverage rates were achieved somewhat later, perhaps because the young American cities did not inherit medieval urban dynamics. For instance, Berlin took about four decades to achieve (near) universal coverage. Helsinki, on the other hand, took much longer. Beyond higher-income economies trends look different. In colonial Calcutta only 14 percent of houses were connected to the mains and Bogotá experienced slow diffusion rates during the late 19th century. Table 2 reveals that that inequalities in access to sanitation were more pronounced than for piped water. Around 1910, a significant majority of the population in London, Berlin, Chicago and Sydney had access to sewers. However, only a third of their counterparts in Helsinki and Calcutta were in the same position. The disparity was even more striking

in Bogotá, where only one in seven citizens had access to this urban amenity by 1938. This latter statistic is interesting when contrasted with the more optimistic view portrayed by table 1: almost half of Colombian cities had built sewerage systems by then, but within-city diffusion was extremely limited.

Notwithstanding the data limitations mentioned above, these patterns indicate that the within-city extension of piped water was even more unequal between countries than their initial construction. What explains such slow diffusion rates? As I will show in section 5, various factors such as social and political discrimination kept the majority of the population away from proper access to water and sanitation, while a minority did enjoy these services and made sure they paid the least amount of money possible.

Table 2. Percentage of the population served by pipes and sewers in some selected cities, ca. 1830-1940

	Water					Sewerage	
	1830	**1870**	**1890**	**1910**	**ca. 1940**	**ca. 1910**	**ca. 1940**
London (England)	88	≈100	-	-	-	≈100	-
Chicago (United States)		≈100	-	-	-	82	-
Berlin (Germany)		43	90	100	-	≈100	-
Helsinki (Finland)		0.5	26	61	85	32	68
Sydney (Australia)		≈60	≈80	100	-	≈80	-
Calcutta (India)		14	-	≈50	-	≈37	-
Bogotá (Colombia)			-	30	59	-	14

Notes: empty cells and hyphens mean that no waterworks were available and unavailable data, respectively.

Sources: in the following I present the sources and the exact interpretation of the figures reported in the table. London: households serviced by water companies (Hardy, 1991, p. 78) and percentage of closets on the water carriage system (Local Government Board, 1913, Appendix I of part 3). Chicago: population served with piped water and sewers (Melosi, 2000, p. 82; US 1860 Population Census). Berlin: share of lots connected to the tap water supply and the sewers (Kappner, 2023, p. 13; 19). Helsinki: housing connected to piped water (the value for 1940 refers to 1930) and with water closets (Peltola & Saaritsa, 2019, pp. 285-286). Sydney: percentage of the population served by water and sewerage connections (de Looper, Booth, & Baffour, 2019, p. 233); the values for 1910 refer to 1908. Calcutta: houses connected to the mains and number of water closets as a percentage of all privies (Goode, 1916, p. 173; 208). Bogotá: buildings supplied with water from the aqueduct (the figure for 1910 refers to 1914) from Felacio Jimenez (2017, p. 90) and the Building Census of 1938: buildings with access to sewers.

After 1950

Systematic cross-country data on safe water and sanitation only becomes available in 2000, making it challenging to track broad developments during the second half of the 20th century. However, we can use the case of Colombia as an illustrative case of the (incomplete) unfolding of the sanitary revolution in a lower-income setting. Nationally, the numbers appear quite impressive: a building census conducted in 2005 revealed that virtually all cities with over 15,000 inhabitants had waterworks and

about 90 percent of these had sewerage systems; these figures are comparable to those in England, Germany or the United States around 1900 (see table 1). Most progress occurred before 1990, although it was highly unequal, with the majority of investments concentrated in urban areas so that slightly less than a third of rural citizens still lacked access to piped water and sewerage in 2017 (Moreno Méndez, 2020, p. 33).

Unfortunately, not all countries have made so much progress in sanitary terms. According to the WHO/UNICEF Joint Monitoring Programme data for 2022, only 66 percent of the urban population in India had access to piped water, while the coverage rate of sewer connections (including shared facilities) was 32 percent. When looking at large regional aggregates, following WHO criteria, we observe that in Africa and South-East Asia piped water in urban areas is accessible to approximately 60 percent of the population, and sewer connections cover between a fourth and a fifth of citizens, respectively. Although comparisons with the data presented in table 1 are not straightforward, the current coverage rates in India and the aforementioned regional aggregates are lower than those of industrialized countries at the beginning of the 20th century.

We can gain an additional perspective on current sanitary challenges in lower-income countries by focusing on city-level data, similar to the information provided in table 2. The cases of Bogotá and Calcutta are instructive. In the former city, by 2005 virtually all citizens had access to the aqueduct and sewerage systems (in one form or another). In Calcutta, on the other hand, only 17 percent of its inhabitants had access to water in their own dwellings, according to the 2019-2021 National Family Health Survey of India (C. Roy, Sati, Biswas, & Kumar, 2023, p. 56). Once again, these comparisons underscore the extent of the sanitary progress in Colombia relative to India, where access to sanitary services nowadays seems more deficient than that of big cities in the United States, England or Germany around 1900 (see table 2).

4. Health consequences of clean water and waste disposal systems[7]

The health impact of the provision of clean water and sewerage during the 19th century has been widely discussed among historians, economic historians, demographers and economists. An earlier literature was divided between those playing down the relative importance of public health

[7] This paper strictly focuses on the health impact of clean water and sanitation, although their welfare and productivity effects might have been substantial. See some studies pointing in this direction, such as Beach, Ferrie, Saavedra, and Troesken (2016) and Gallardo-Albarrán (2018, 2019). Also, this section considers historical work and does not delve into research investigating the health impact of sanitary infrastructures more recently (e.g. Bhalotra, Diaz-Cayeros, Miller, Miranda, & Venkataramani, 2021; Zwane & Kremer, 2007).

infrastructures on mortality (Fogel, 1994; McKeown, 1976),[8] and scholars highlighting their beneficial effects. An example of the latter is Szreter (1988), who reconsidered the British experience and claimed that local sanitary reform greatly reduced the incidence of infectious disease with the improvement of drinking water, waste removal and food market regulation. Easterlin (1999) supports this view and the idea that economic growth, and market forces in particular, could not account for the modern history of mortality due to information failure, externalities and public goods under provision. Instead, the key factor was the diffusion of social and political movements that pushed for a sanitary revolution, in public and private domains, with the help of local administrations (Mokyr & Stein, 1996).

In the mid-2000s, a series of econometric studies were conducted with the aim of examining the precise impact of sanitary reform on mortality trends.[9] Troesken (2004) analyzed various major American cities and concluded that improvements in their water purification systems were the fundamental drivers of declines in waterborne diseases, such as typhoid fever and diarrhea, at the turn of the 20th century. Similarly, Cutler and Miller (2005) estimated that large proportions of the mortality decline in American cities between 1900 and 1936 were due to water purification (i.e. chlorination and filtration). Since then a number of articles have followed their footsteps, although comparing their findings systematically can be difficult because they use different econometric specifications, mortality variables and measures of clean water and sewerage. To overcome these difficulties, this survey first focuses on quantitative exercises that, following Cutler and Miller (2005), share two important characteristics: the use of a log-transformed outcome variable and indicator (dummy) independent variables. A common way to model the impact of public health interventions is as follows:

$$\log(mort_{it}) = \alpha + \beta_1 \text{intervention1}_{it} + \beta_2 \text{intervention2}_{it} + \beta_3(\text{intervention1}_{it} + \text{intervention2}_{it}) + \Theta X_{it} + \delta_i + \pi_t + \varepsilon_{it}, \quad (1)$$

where *i* and *t* index city and year, respectively; *mort* is a mortality variable, such as crude death rates or infant mortality rates; *intervention1 and intervention2* are dummy variables turning one when a public health intervention occurs in a given city and year; *X* is a vector of controls; δ_i and π_t are city- and year-fixed effects; and ε is the error term. The vector of controls typically includes demographic characteristics of the population (e.g. the composition of the population in terms of age, sex or ethnicity), urban congestion indicators (e.g. population density or demographic growth) and industrialization and income indices (e.g. share of workers employed in manufacturing). In some cases, other public health measures are included to avoid that the coefficients of interest pick up their effect,

[8] In later work, Fogel (2004, p. 37) argued that public health investments after 1870, such as water and milk purification (among other things), were responsible for mortality reductions during the first decades of the 20th century.

[9] Earlier quantitative studies taking a different quantitative approach include van Poppel and van der Heijden (1997) for the Netherlands and Brown (2000a) for Germany.

such as food and milk inspections or hospital construction. Finally, city-specific linear trends are sometimes employed to control more flexibly for factors that influence health outcomes over time in a way that varies across cities.

Three aspects of equation 1 are worth mentioning. First, the literature has used two types of dependent variables: disease-specific and all-cause mortality. The former typically refers to waterborne diseases transmitted via fecal-oral mechanisms, which are likely to be influenced by water filtration and chlorination. A classic example is typhoid fever which was historically used as a marker of water quality, because epidemic outbreaks were associated with the ingestion of pathogens in drinking water, similarly to cholera and dysentery transmissions.[10] The second type of dependent variables relies on all-cause mortality, often focusing on infant or child mortality who are particularly susceptible to gastrointestinal diseases. Using one of these two types of dependent variables has advantages and disadvantages. Information on causes of death allows for a better identification of the mechanisms linking population health and access to sanitary infrastructures. However, misdiagnosis could lead to measurement error in some contexts where deaths were not certified by doctors until well into the 20th century. Overall and child mortality, on the other hand, do not suffer from this issue, but they contain information on deaths due to diseases that are not necessarily related to sanitary infrastructures, such as whooping cough, measles, smallpox or cancer. A combination of the two is probably the best approach to find meaningful and robust relationships.

The second aspect of equation 1 to be highlighted concerns the proper identification of the coefficients of interest. The literature often argues that endogeneity (due to simultaneity bias) is not a major source of concern, because the precise timing of waterworks and sewerage are largely independent of local mortality. While these are not completely unrelated, of course, the history of public health contains a myriad of cases in which well-intended efforts to improve the sanitary conditions of cities were often trumped by self-interested economic and political elites. This narrative finds quantitative support in the Swedish and German cases where mortality levels were not systematically higher five years before cities implemented piped water services (Gallardo-Albarrán, 2020, Appendix S2; Helgertz & Önnerfors, 2019, p. 321). At the same time, the coefficients of interest (β_1, β_2 and β_3) would not be well identified if we do not take into account factors that likely correlate with both mortality and investments in public health, such as levels of municipal wealth, education and upper-tail technical knowledge. One strategy to strengthen the credibility of the results from estimating equation 1 is to demonstrate that investment decisions are not associated with the immediate implementation of waterworks and sewerage, as shown by Helgertz and Önnerfors (2019). Another strategy involves leveraging plausibly

[10] Not all ailments causing diarrhea are highly dependent on access to clean water, since pathogens causing this symptom, such as *E. coli*, were more related to food poisoning (Davenport, Satchell, & Shaw-Taylor, 2019).

exogeneous sources of variation, as done by Alsan and Goldin (2019) through geographic factors, but such sources are unfortunately rare. One final technical challenge associated with using dummy variables in equation 1, particularly when employing staggered treatment variables in difference-in-differences (DiD) settings, is that they can lead to estimates that are not easily interpretable. The articles mentioned in this section have not dealt with this potential challenge, leaving uncertainty about how their estimates would vary if accounted for it. Theoretically, staggered DiD estimates can have the opposite sign of their true average treatment effect in the presence of treatment effects that vary over time (A. C. Baker, Larcker, & Wang, 2022).

The third important feature of equation 1 is that the relevant regression coefficients answer a similar question: *what is the (log) mortality change associated with one or several public health interventions after the initial year of operation?* Note that the formulation of this question in percentage terms is useful for temporal and spatial comparisons, since it can be applied to contexts with different levels of mortality.

Table 3 presents the results from a number of articles that were published between 2005 and 2022. To ensure comparability, the reported coefficients come from specifications that closely resemble equation 1. Also, I prioritize the 'main' or 'preferred' models by the authors, provided they are similar to equation 1. The coefficients are displayed in three columns: 'clean water' that typically refers to waterworks construction, filtration or chlorination; 'sewerage' refers to sewage disposal and treatment; and 'both' considers their joint effect. Since the literature often investigates various water supply and waste disposal technologies, the last column contains information on the specific variables used in each study and whether interaction effects were employed. For instance, Cutler and Miller (2005) examine the effect of water filtration and chlorination. Their individual impact (β_1 and β_2) is reported in table 3 ('clean water' column) as well as their joint impact including their interaction (last column). Their estimates imply that water filtration was associated with sizeable mortality declines, especially infant mortality rates: 0.43 log points. Considering their joint effect with chlorination, they account for about 50 percent of the total decrease in infant deaths in big American cities between 1900 and 1936.[11] Death rates from typhoid fever, which serve as a sensitive measure of water quality as mentioned earlier, declined by 0.25 log points following the introduction of filtration and chlorination. D. M. Anderson, Charles, and Rees (2022) indicate that these estimates are too high. In their replication exercise, they found that after accounting for errors in public health intervention

[11] The original calculations contained errors, as pointed out by Alsan and Goldin (2019, p. 588). The authors have published a note revising them entitled *Erratum: "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States":* https://ngmiller.people.stanford.edu/sites/g/files/sbiybj24836/files/media/file/erratum.pdf [accessed on 18-07-2023].

dates and infant mortality, the filtration variable coefficient declines by more than 90 percent. While these revised results are more rigorous and robust, they should not be misinterpreted to imply that public health interventions had no impact on infant mortality, or other health outcomes. First, their own analysis using an extended 25-city sample and a larger number of public health interventions (e.g. sewage treatment or bacteriological milk tests) demonstrates that water filtration is associated with an 11-12 percent decline in infant mortality. Second, although their water filtration coefficient is -0.17 when using typhoid fever as dependent variable, about 60 percent lower than that by Cutler and Miller (2005), Beach, Ferrie, et al. (2016) estimated coefficients ranging between -0.24 and -0.35 drawing on a comprehensive 61-city panel for the period 1880-1920. Also, Beach, Troesken, and Tynan (2016) showed that the municipalization of waterworks in England explains nearly 20 percent of the decline of typhoid fever between 1869 and 1910. Third, several studies have highlighted the joint importance of waterworks and sewerage in promoting a less hazardous disease environment (more on this below). Fourth, and perhaps most importantly, the evidence presented by these authors primarily focuses on a limited number of large American cities during the first four decades of the 20th century. This limited empirical basis makes it difficult to conclude that public health interventions did not play an important role in the decline of urban mortality. This issue is even more salient in light of the evidence from the other side of the Atlantic, that presents negative impacts on mortality after water supply improvements were made for Switzerland (Floris & Staub, 2019) and Sweden (Helgertz & Önnerfors, 2019). For the case of Finland, Peltola and Saaritsa (2019) chlorination matters greatly as infant mortality declined by 0.19 log points after their implementation. Overall, table 3 shows that the water variable coefficients from these studies are still quantitatively significant although smaller than initially claimed by Cutler and Miller (2005): for IMR and waterborne diseases they range between -0.09 and -0.19 and -0.22 and -0.26, respectively.

Table 3. Mortality impact of public health interventions

Study	Country (period)	Mortality measure	Clean water	Sewerage	Both	Source; variables used and additional information on the regression coefficients
Cutler and Miller (2005)	United States (1900-1936)	CDR	-0.16**/-0.02	-	-	Table 5, col. 3 (p. 13); water filtration and chlorination (their joint effect, including their interaction, is -0.13**)
		IMR	-0.43**/-0.08	-	-	Table 5, col. 4 (p. 13); water filtration and chlorination (their joint effect, including their interaction, is -0.46**)
		Typhoid	-0.46**/-0.11	-	-	Table 5, col. 2 (p. 13); water filtration and chlorination (their joint effect, including their interaction, is -0.25*)
Beach et al. (2016)	United States (1880-1920)	Typhoid	-0.24* – -0.35*	-	-	Table 1, cols. 5 and 10 (p. 50); water filtration
Alsan and Goldin (2019)	United States (1880-1920)	CMR	0.11	-0.07	-0.27***	Table 2 (p. 605), col. 5; safe water and sewerage ('Both' includes their interaction and its coefficient is -0.31***)
	United States (1880-1920)	IMR	0.04	-0.09*	-0.23**	Table 2 (p. 624), col. 10; safe water and sewerage ('Both' includes their interaction and its coefficient is -0.18*)
Anderson et al. (2022)	United States (1900-1940)	CDR	-0.01/0.01/-0.01	0.02	-	Table 6 (p. 140), col. 5; water filtration, chlorination and completed clean water project (for 'Clean water'), and sewage treatment/diversion ('Both' is missing since interactions are not included in the model)
		IMR	-0.11*/0.08/-0.06	0.04	-	Table 7 (p. 141), col. 5; water filtration, chlorination and completed clean water project (for 'clean water'), and sewage treatment/diversion ('Both' is missing since interactions are not included in the model)
Gallardo-Albarrán (2020)	Germany (1877-1913)	CDR	-0.02	-0.09***	-0.11***	Table 2 (p. 745), col. 6; water supply and waste disposal improvements ('Both' includes an interaction implicitly, because all cities in the sample had waterworks when they built sewerage systems)
		IMR	-0.04**	-0.07***	-0.11***	Table 3 (p. 746), col. 6; water supply and waste disposal improvements ('Both' includes an interaction implicitly, because all cities in the sample had waterworks when they built sewerage systems)
		Waterborne diseases	-0.07	-0.23***	0.29***	Table 4 (p. 749), col. 1; water supply and waste disposal improvements ('Both' includes an interaction implicitly, because all cities in the sample had waterworks when they built sewerage systems)
Floris and Staub (2019)	Switzerland (1876-1901)	IMR	-0.09	0.06	-0.05	Table 5 (p. 266), col. 12 for water/sewerage; central water supply and sewage renewal ('Both' includes their interaction and its coefficient is -0.02)
		Typhoid fever	-0.25	0.20	-0.26	Table 3 (p. 263), col. 4 for water/sewerage and 4 for both; central water supply and sewage renewal ('Both' includes their interaction and its coefficient is -0.21)
Peltola and Saaritsa (2019)	Finland (1870-1938)	IMR	-0.13/-0.19**	-0.08**	-0.31***	Table 7 (p. 289), col. V; piped water and chlorination, and sewers ('Both' includes an interaction between piped water and sewers and its coefficient is 0.10)
Helgertz and Onnefors (2019)	Sweden (1875-1930)	CDR	-0.17***		-	Table 7 (p. 331), col. 22; the coefficient refers to 'water and/or sewerage'
		IMR	-0.17**		-	Table 7 (p. 331), col. 23; the coefficient refers to 'water and/or sewerage'
		Waterborne diseases	-0.22**		-	Table 7 (p. 331), col. 21; the coefficient refers to 'water and/or sewerage'

Note: *p<0.1, **p<0.05, ***p<0.01. The coefficients reported come from a single specification reported in each study.

What can explain the limited effects of piped water? One reason can be that the prevalence of ailments transmitted through fecal-oral mechanisms does not exclusively depend on clean water provision, but also on proper and efficient systems of waste disposal. Clean water can be polluted during transport or in the household (Kremer, Leino, Miguel, & Zwane, 2011), and the inappropriate storage and removal of human excrement increases exposure to enteric diseases (Kesztenbaum & Rosenthal, 2017). In line with this idea, Alsan and Goldin (2019) find that water and sanitation technologies are complementary and that they caused a third of the child mortality decline in Massachusetts between 1880-1920. Similarly, Gallardo-Albarrán (2020) indicates that the effect of waterworks on mortality in Germany were limited in the absence of efficient systems of waste disposal. His coefficients for IMR are slightly smaller than those of Alsan and Goldin (2019), but still sizeable since they account for 25 per cent of the decrease in infant mortality in Germany. Interestingly, the mechanisms just described are not found everywhere, as the evidence for Switzerland and Finland show, which suggests that they might mostly apply to industrialized settings. This could be explained by a close correlation between industrialization and more rapid urban growth and overcrowding as well as additional pollution caused by the discharge of wastewater of factories, although this hypothesis requires deeper investigation.

The studies mentioned thus far focus on easily observable public health interventions and do not consider who had access to sewers and pipes, which may be more relevant for health outcomes. Partially addressing this issue, and not without some of the endogeneity concerns mentioned above, other work has used coverage information. For instance, Jaramillo-Echeverri, Meisel-Roca, and Teresa Ramírez-Giraldo (2019) analyze the decline of mortality in Colombia between 1916 and 2014 and find that gastrointestinal mortality decreased 13-16 percent and 7-8 percent when about a third of the population in a municipality had access to the aqueduct and sewerage systems, respectively. Looking at the adoption of tap water in interwar Tokyo, Ogasawara, Shirota, and Kobayashi (2018) estimate that the increasing number of taps per 100 households accounts for 35 percent of the drop in IMR between 1921 and 1937.[12] This study is important because, as mentioned in the previous section, complete coverage was often reached decades later after the initial construction of infrastructures, which hindered the full eradication of waterborne diseases. Tokyo built waterworks in 1898 and an important part of its effects was not visible until about three decades later. A second indicator measuring the intensive margin of public health interventions is spending. For England and Wales, Chapman (2019) finds that overall infrastructure spending (e.g. clean water, street paving, sewerage,

[12] Quantitative evidence from other countries, such as Estonia, Australia or Greece, suggests that access to clean water was an important determinant of urban mortality (de Looper et al., 2019; Jaadla & Puur, 2016; Raftakis, 2023). These articles are not included in table 3 due to the different nature of their analyses.

etc.) caused up to 60 percent of the mortality drop during the last four decades of the 19th century.[13] A more recent article by the same author shows that 20 percent of the decline in infant mortality between 1881 and 1911 can be explained by sanitation investment (Chapman, 2022b). Aidt, Davenport, and Gray (2023) have extended this work in two important ways for the purposes of this review: they have assessed the individual contribution of water and sewerage investments, and they have pushed the analyzed period back to 1845. In line with earlier evidence on the importance of sewerage systems, they are associated with declines in infant mortality between 1880 and 1909. Before the 1880s, though, clean water seems to have mattered much more, as their estimates imply that it explains about 40 percent of the decline in infant mortality. These numbers have to be interpreted carefully, given that mortality in some the sampled cities did not fall by much.

Until now, I have not considered that public health interventions can influence mortality outcomes indirectly. For instance, waterborne sicknesses with severe symptoms can weaken the immune systems of individuals and can make them more vulnerable to other diseases, such as respiratory ailments. Evidence for this mechanism has been put forward for Chicago by Ferrie and Troesken (2008, p. 13) who calculate that four to seven deaths happened for every additional death from typhoid fever during the late 19th century. This finding, however, refers to a single city and one might wonder about its representativeness. In the Japanese context, Inoue and Ogasawara (2020, p. 5) analyze more than a hundred cities and find that this phenomenon was at work, although the effect was much smaller: between 0.9 and 1 deaths. In addition, indirect evidence of this mechanism can be observed in a number of studies that use CDR as dependent variables, and still find sizeable declines in mortality after sanitary investments were made (e.g. Chapman, 2019; Gallardo-Albarrán, 2020; Ogasawara et al., 2018).

Heterogeneity in the effects of water and sanitation

One implication of the accumulating body of evidence generated in the last few years is that the health impact of effective water supply and waste disposal differs substantially across contexts and time periods. Most importantly, it points to the need of acquiring a more detailed knowledge of local contexts to understand their interplay with public health measures. In line with this idea, Gallardo-Albarrán (2020) finds that sanitation was more effective in cities with a strong presence of the textile sector in the local economy. The importance of female labor in this sector may have led to lower levels of breastfeeding and thus a higher reliance on contaminated water sources. Also, textile industries

[13] Not everyone agrees with this, however. Harris and Hinde (2019) argue that Chapman (2019) does not consider loans themselves, but rather the amounts that had to be repaid (outstanding loans). This makes it difficult to assess when sanitary investments took place, given that a town might have taken a loan many years before making the actual investment.

(e.g. dyeworks and textile finishing) may have led to pollution issues that were alleviated with the arrival of proper waste disposal. Another local element interacting with public health interventions highlighted in this study is inequality. Less egalitarian contexts may have led to widespread misery that, in turn, may have discouraged citizens from paying sanitary fees. To the extent that urban infrastructures reached a large part of the population, mortality levels converged (D. M. Anderson, Charles, Rees, & Wang, 2021). Peltola and Saaritsa (2019) emphasize a different dimension in the Finnish experience: population size. According to their results, most of the effect of sanitation was due to their performance in smaller cities because early movers (bigger municipalities) might have suffered from lack of complementary inputs.[14] In other words, the mere provision of piped water may not be enough in contexts characterized by poverty, lack of hygiene, overcrowding and little human. In a similar fashion, access to sewerage in England was strongly associated with mortality declines after 1880, while water provision seemed to have been important for infant and child mortality during the period 1845-1884 (Aidt et al., 2023).

Another element interacting with the health effect of waterworks concerns environmental conditions, as temperatures and humidity (among others) influence the mobility and survival of pathogens and vectors. Therefore, having access to clean water and proper waste disposal has the potential of providing greater community protection from the seasonality of certain diseases in some places than in others. This idea receives support from Ogasawara and Matsushita (2019) who observe that safe water had a larger impact on the reduction of typhoid death rates in Japanese cities with higher temperatures during the interwar period. On the other hand, D. M. Anderson, Rees, and Wang (2020) do not find an impact of water filtration on diarrhoeal deaths during summer, but rather during non-summer months.

Finally, the effectiveness of waterworks also depends on technical considerations, such as their ability to supply a constant service. Troesken et al. (2021) examine this for London between 1860 and 1910, a period marking the complete transition to uninterrupted water service, and conclude that it explains between 20 and 30 percent of the decline in waterborne diseases. This factor is likely important in many other contexts, since problems with temporary interruptions and low pressure were rather common during the 19th century, as they are nowadays in developing countries as well. Another technical aspect concerns the materials employed for the distribution network, such as lead that was often used for pipes connecting water mains with households due to cost issues.[15] The direct and

[14] The designation of 'city' in some Scandinavian contexts was granted by the Crown and therefore was not necessarily correlated with current or future population size.

[15] Pipe degradation attenuates the impact of waterworks, since it decreases the quality of water (Bhalotra et al., 2021).

indirect consumption of lead dissolving in the interior of pipes led to the poisoning of adults and children alike. In large quantities, it could cause anemia, neurological damage or kidney failure. Infants were particularly vulnerable, because exposure began in the womb and continued throughout the breastfeeding period (Troesken, 2008). Clay, Troesken, and Haines (2014) calculate that leaching of lead resulted in significantly higher infant mortality rates in the United States, where the use of lead pipes was widespread; and Feigenbaum and Muller (2016) argue that lead exposure increased homicide rates.

The evidence presented in this section conveys, broadly speaking, three main messages. First, the impact of safe water on mortality, while substantial, seems lower than initially thought. In the absence of efficient systems of waste disposal, the efficiency of waterworks is impaired. Second, the effectiveness of public health interventions interacts with socioeconomic factors (e.g. economic structure of the population or inequality), technical features of infrastructures (e.g. capacity and materials) and environmental conditions (e.g. temperature and humidity changes). And third, as a result of the first two, earlier debates focusing mostly on 'nutrition versus sanitation' as important factors accounting for the decline of mortality were too simplistic. We should pay much more attention to the conditions that make sanitary reforms succeed or fail. A research agenda in this direction includes extending our analyses to other world regions and periods, including rural settings where these investments were made much later and thus the benefits may have been greater. In line with this idea, Hoehn-Velasco (2018) finds that sanitation and child-oriented health services had a larger impact in rural-only regions in the United States between 1908 and 1933. In addition, a careful estimation of neighborhood and regional spillover effects could shed light on the relative importance of spatial factors operating beyond the household context. For current-day India, for instance, Geruso and Spears (2018) find that the negative externalities due to poor sanitation have a large impact on the survival prospects of infants. Finally, the field could consider how synergies between sanitary infrastructures and net nutritional status influence each other: morbidity declines lead to higher productivity and human capital, which in turn improve future individual income and nutrition.

5. Drivers of investment in waterworks and sanitation

It is a most challenging task to explain the patterns of diffusion of sanitary infrastructures identified in section 3, or within any given country.[16] One approach consists of focusing on purely economic conditions of supply and demand in the market of water and sanitation, such as the willingness to pay by consumers or how their demand is met by suppliers according to their marginal cost. This approach,

[16] One should distinguish between construction and operation of water and sanitation projects, since these require different sets of inputs. This survey, though, focuses mostly on the former because it has received far more attention.

however, has been criticized because it ignores the political embedding of markets (C. M. Rosen, 1986), especially in a time where their allocative efficiency in the public health sector was heavily impaired due to imperfect information, externalities or information asymmetries (Easterlin, 1999). Also, theoretically, demand mechanisms are hardly effective in the presence of a large number of consumers that might be aware of the benefits of making sure their complaints are heard, but the individual costs borne by them are too high (e.g. Olson, 1965). This is not to say that local economic conditions are unimportant to understand the rise of modern sanitation during the 19th-century but, rather, that one should not analyze them in isolation.

A more fruitful approach models the political process by understanding how elements of public finance affects the willingness of political actors to embark on sanitary reform (e.g. Aidt, Daunton, & Dutta, 2010; Brown, 1988).[17] Political economy studies pay special attention to questions surrounding the fiscal system, such as the amount of taxes raised by municipalities and their spending autonomy; who finances local budgets; the connection between tax payments and political representation; or how expenditures benefits those paying taxes. These mechanisms are important for communities where private companies operated, since they might determine their choice of funding.

This survey argues that the economic and political mechanisms mentioned above operate within broader institutional, cultural and biogeographic contexts that produce constraints and opportunities to invest in water and sanitation infrastructures. I distinguish between *proximate* and *ultimate* factors drawing on the economic growth literature (e.g. Gallardo-Albarrán & Inklaar, 2021; Rodrik, 2003). Proximate drivers refer to inputs of a production process that are easily observable and required to offer sanitary services, such as physical and human capital. On the other hand, ultimate drivers operate indirectly and over a longer time frame via supply or demand forces. A supply-side example is how the national institutional embedding of a municipality (ultimate factor) regulates the functioning of national and local financial markets to finance the acquisition of expensive steam engines and water mains (physical capital) and skilled engineers (human capital). Without the existence of a clear set of rules that discourage opportunistic behavior or political corruption, the allocation of scarce financial resources will be greatly impaired. For a demand-side mechanism consider how the biogeographic characteristics of a country (e.g. temperatures, humidity, presence of disease vectors) impact the probability of suffering from certain epidemics, which in turn increase demand for a cleaner disease environment. Or consider how cultural attitudes and beliefs towards certain groups of the population,

[17] Although these approaches are the most used in historical work, these are by no means the only ones available; see Banerjee, Iyer, and Somanathan (2006). Also, C. M. Rosen (1986) conceptualizes the process of infrastructural investment as a set of interactions between economic and demographic stimuli and their necessary adaptations caused by such interactions. These relationships, in turn, are mediated by a variety of frictions that delay and distort the articulation of community demands and supply.

such as racial or religious discrimination, influence the willingness of providing universal access to urban infrastructures.

This framework has several conceptual advantages. First, unlike traditional supply-demand models, it separates factors that are slow-moving and difficult to influence (and measure) from those that are under a more direct control of local governments and companies. This distinction has the potential of explaining some of the between- and within-country patterns described in section 3. For instance, one might invoke institutional or cultural reasons to interpret the slow diffusion of waterworks in Colombia during the 20th century, but these have little explanatory power when looking at differences between, say, Medellín or Bogotá. Second, covering various types of proximate determinants provides a richer perspective on the constraints and opportunities faced by different communities. Physical and human capital were not available everywhere to the same extent, and this may hint at why some cities acquired them faster than others, or why they often had to be imported from abroad. Third, the distinction between proximate and ultimate factors allow for encompassing different branches of the literature into a unified framework. This will bring about a number of underexplored research avenues that, I think, are critical to explain the long-term temporal and spatial trajectory of the sanitary revolution.

5.1 Proximate determinants

Proximate determinants are (humanly produced) basic inputs that are needed to build waterworks and sewerage systems, such as physical infrastructure, human capital and technology.[18]

Physical infrastructures

They refer to buildings and equipment that are employed to bring water to final users (e.g. pumping stations, mains and secondary pipes, reservoirs) and to carry away waste (e.g. sewers and sewage treatment facilities). These are capital intensive and land extensive, in that their construction is costly and requires a substantial amount of space to be deployed. In addition, their construction and operation entail high fixed costs and economies of scale that result in a monopolistic type of production. On the basis of these characteristics, in the following I elaborate on two aspects that can affect the timing of waterworks and sewerage: construction costs and complementarities with other urban networks.

[18] One might consider 'improved' or 'adjusted' land as a fourth input, which is particularly relevant for issues of property rights governing the public space. However, I have omitted it from this review because this is rarely considered in quantitative historical studies. Historians, on the other hand, mention it (Millward, 2000, p. 321; Reulecke, 1985; C. M. Rosen, 1986, p. 227)

The elevated cost of physical infrastructures, especially at the outset, is probably one of the most-invoked reasons on why some places spend more or earlier on them than others. Not only do international development agencies emphasize the importance of better and more funding to ensure sanitation for all in the upcoming decades, but also governments often referred to lack of resources in the past. In India and Colombia, for instance, sanitary spending was intimately linked to local finance and tax revenues (Felacio Jimenez, 2017; Harrison, 1994, pp. 171-172). To get a sense of the spending efforts by municipalities, Troesken (2015, p. 115) compares the costs, in constant 2011 dollars, of various large public works projects in American history. Consider the transcontinental railroad and the Old Croton Aqueduct to supply New York, which cost 1780 and 336 million, respectively. On a per-capita basis the latter was much more expensive (about 20 times) because even though its absolute cost was lower, it served a much reduced number of citizens and was funded by a smaller tax base. In Germany, sanitary infrastructures pushed up debt levels so that around 1910 one fifth of the debt of municipalities larger than 50,000 was due to water- and canal-related investments; for comparison, this amount was slightly more than one third in large American cities (Brown, 2000b, p. 254).

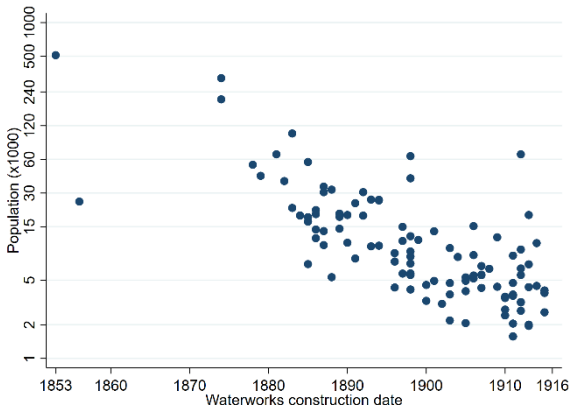
In relation to construction costs, it makes sense intuitively and theoretically to take into account how urban agglomerations present opportunities for the establishment of large-scale sanitary infrastructures. Initial high disbursements can be divided among a larger client base, thus leading to lower per-capita construction and operation expenses. Furthermore, in densely populated areas the underground network reaches a larger amount of inhabitants per square meter. This could explain one of the patterns of waterworks diffusion identified in section 3, namely that many major cities across the world built them between 1850 and 1900. At the same time, the predictive power of this factor is somewhat limited because some cities with similar construction dates – e.g. Hamburg (1849) and New York (1842) – differed greatly in size. Admittedly, these are just illustrative examples and so future research should perform a more systematic analysis to understand the relevance of this mechanism, by also adding population density and other characteristics of urban development.

Within countries, however, the evidence on population size and the timing public health interventions is somewhat more robust. Figure 1 shows this visually by plotting data on waterworks construction dates against population size around 1900 in various countries: The Netherlands, Finland, Germany and the United States. Generally speaking, there is a negative correlation between these variables, meaning that larger cities in 1900, which were typically bigger in the past, constructed waterworks earlier than smaller cities. This correlation is clearly stronger in the Dutch and Finnish cases (see panels A and B, respectively) although far from perfect. In Germany (see panel C), the relationship seems weaker as the degree of variation is quite significant; see how the timing of these infrastructures in cities with about 60,000 inhabitants that ranged from the 1860s to the 1900s. The same can be

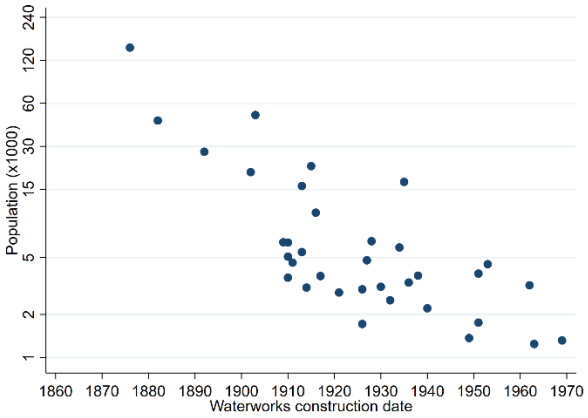
observed for the United States, where various municipalities with about 30,000 citizens had tap water systems throughout the 19th century.

Figure 1. Population and the timing of waterworks

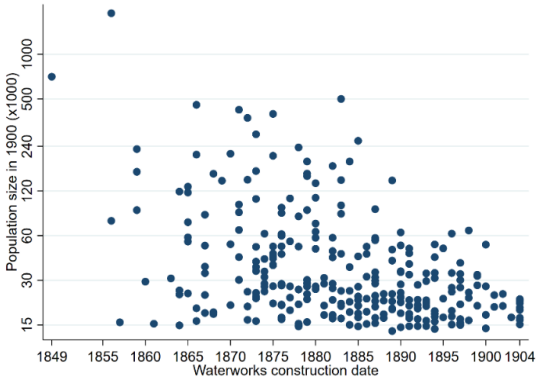
Panel A: The Netherlands



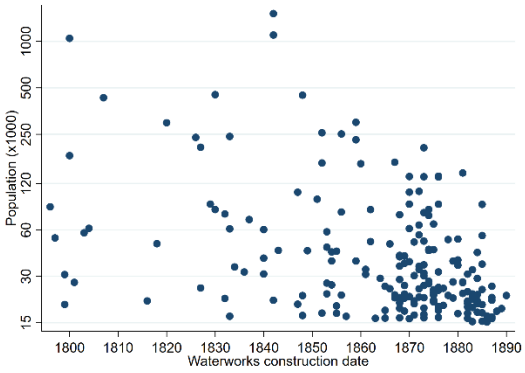
Panel B: Finland



Panel C: Germany



Panel D: The United States



Source: see table 1 for Germany, the Netherlands and the United States; Peltola and Saaritsa (2019) for Finland. Population for the United States refer to 1890; for Germany to 1904; for the Netherlands to 1899; and for Finland to 1910.

Although the simple correlations presented in figure 1 are not to be interpreted causally, there are a number of studies from the literature suggesting this. In Germany, building costs were paramount for the construction of waterworks (Brown, 1988). For the United Kingdom, Millward (2000, p. 321) argues that larger municipalities and companies had an advantage in affording the costs of issuing stocks and obtaining parliamentary bills. These sources of financing were superior than those offered by the Public Works Loan Board, which entailed high interest rates and short repayment periods. Chapman (2022b) provides additional quantitative analysis of how important financial constraints were in

England. Falling interest rates during the late 19th century stimulated borrowing and investment in sanitary infrastructure. Similarly, Cutler and Miller (2006) bring to the forefront the role of capital and changes in American local public finance. They maintain that costs were too large for private firms and cities with a relatively small tax base. In fact, the value of municipal waterworks was so high that they exceeded yearly local government revenue, sometimes, by more than a factor of two.

Another factor influencing the ability of municipalities to secure stable amounts of funding involves the changing real price of materials and construction costs. Rises in productivity, and in the construction and utilities sectors in particular, would ease the financial constraints smaller cities faced as the real cost of infrastructural investment went down. These economic forces were at play during the 19th century in the United Kingdom and the United States (Bakker, Crafts, & Woltjer, 2019, p. 2278; Feinstein, 1972, pp. T111-T112) and in large number of countries during the 20th century (Gallardo-Albarrán & Inklaar, 2021). Therefore, it is not surprising to find historical evidence indicating that the adoption of steam-powered engines was not cost efficient at first and that widespread adoption came later, as in France (Guillerme, 1988, p. 99).

After discussing the sheer costs of physical capital, I now turn to another feature of infrastructural improvements: complementarities with other urban services, such as firefighting. This became an enormous challenge during the 19th century when demographic change coupled with overcrowding, poor housing standards and lack of urban planning led to frequent and devastating fires. A well-known case is that of Hamburg in 1842 that revealed the urgent need of firefighters to secure an abundant and quick provision of water. In other German places, historical accounts suggest that this was a major reason for cities to construct waterworks, but it is difficult to determine how important this issue was given that Hamburg was rather unique. For other cities, such as San Francisco, similar arguments have been made (Frost, 2020, pp. 19-20). Besides firefighting, the provision of electricity and gas also interacted with that of water and sanitation, especially if these required reworking public streets. From the perspective of a municipality, it was more cost efficient to lay out different elements of an encompassing urban network at once, as the fixed expenditures of street digging could be incurred just once. A second type of complementarity arises in the financial domain because municipalities sometimes cross-subsidized urban amenities using revenues from more profitable ones, such gas provision (Millward, 2000, p. 334). The last type of complementarity involves the interaction between the need of sewers to be flushed regularly or how the introduction of abundant water in a city requires an efficient network of sewers to dispose wastewater. In other words, one might argue that once one of these infrastructures was built, the additional needs it created made it 'inevitable' for the other type to be constructed.

Human capital

Knowledge and skills were crucial for the proper design, construction and operation of waterworks. Among other things, experts such as engineers or geologists had to gauge the availability of water in nearby sources in relation to current and expected population figures; assess the elevation of the city and water reservoirs to make use of gravity to distribute water; choose a proper location for sewage outlets and weigh the impact on the environment; ensure that pipes and sewers did not get stuck or leaked; etcetera.

The technical capability of British engineers was quite evident around the mid-19th century, when they were hired to carry out the construction of large-scale infrastructures in different European countries, such as Germany or Spain (Mohajeri, 2005, p. 50; Sánchez Gómez, 2016). Beyond Europe, British experts were involved in a number of complex works in the American continent and in colonies in Africa and Asia. Indeed, many found employment in India during the process of colonial expansion after the mid-19th century to work on railway lines, irrigation schemes, waterworks or canals (Buchanan, 1986). The extent to which engineering knowledge scarcity was a relevant factor is hard to assess, but it probably was more important during the 1850s and 1860s when large-scale health infrastructures were relatively rare. Indeed, Reulecke (1985) explains how the lack of German know-how in this domain at the time represented a constraint for producing large-scale infrastructures. After that, though, the civil engineer became an established profession along with the development of German polytechnical universities. In the United States, civil engineering was established as a field of specialization by the 1880s (L. Anderson, 1984, p. 223). After a while, French and German companies were also active internationally as illustrated by the experience of the Ottoman Empire (Dinçkal, 2008).

Technology

Technology can be generally understood as knowledge increasing the effectiveness with which inputs are turned into output. In our context, it can refer to ideas, techniques or procedures leading to better combinations of physical and human assets that, in turn, result in more efficient systems of water supply and waste disposal. Some examples include the understanding of soil types and pipe corrosion, more accurate topographical analyses to determine the location and design of projects, or better knowledge of the creation and maintenance of steam engines. This type of knowledge was transmitted in forums that engineers created to get access to the latest developments in the field, such as the American Water Works Association founded in 1880, or the German association of gas and water experts that started disseminating systematic information about waterworks since 1870 (Deutschen Vereins von Gas- und Wasserfachmännern, 1870, pp. 49-51). In addition, the professionalization of the discipline mentioned above ensured that new technologies diffused widely and efficiently to the extent

that, according to L. Anderson (1984, p. 223), receiving proper engineering information played a role in the adoption of waterworks after 1880 in the United States.

Another factor that can increase productivity refers to organizational aspects of the production process. The literature on economic development has argued that better management can be understood as a technology (Gallardo-Albarrán, 2023). In this respect, ownership might be relevant, given that private companies are often blamed for being profit-driven. This, according to some, makes them incapable of internalizing the positive externalities of providing water and sanitation services, which leads to worse outcomes in terms of coverage since they will tend to only cover the most profitable areas of a city (Beach, Troesken, et al., 2016). On the other hand, public enterprises motivated to deliver the greatest public good do internalize externalities and lead to wider access to waterworks. This argumentation was often made by politicians to municipalize waterworks, although that American private companies were much more likely to implement filtration systems by 1899 (Troesken, 1999). Public companies, however, may have boosted water demand since they tended to charge lower rates than private enterprises.

Summing up

This section has reviewed a number of mechanisms associated with concrete characteristics of physical and human capital and productivity that can explain why some places might have invested earlier in waterworks and sewerage than others. However, while there is substantial quantitative evidence about the importance of costs and access to finance, more research is needed to quantify other mechanisms for which I have mostly drawn on qualitative literature. One of these relates to how the provision of different public goods can reinforce each other and incentivize public health interventions. If such complementarities lead to a relatively high 'multiplier effect', this might be a potentially important factor for both between- and within-country patterns of sanitary diffusion. In a similar fashion, the diffusion of engineering knowledge and technological innovation can provide opportunities for cities located within the sphere of knowledge networks. Finally, the operative efficiency of private and public companies might be important, although in many contexts most companies were municipalized by the first decade of the 20th century.

5.2 Ultimate determinants

Ultimate determinants tend to persist over long periods of time and affect the establishment of sanitary infrastructures through demand or supply mechanisms. In this article, I elaborate on three: economic and political institutions, biogeography and culture.

Institutions

Economic and political institutions regulate and incentivize how public and private actors interact with each other when dealing with the production, distribution and consumption of goods and services. The idea that inclusive institutions are conducive towards public health spending has some support in the literature. For 19th-century England, Deaton (2013) claims that new political coalitions resulting from the enfranchisement of working men were needed to install clean water systems. High-income citizens did not pay much attention (or even obstructed) public spending to avoid future tax raises. Then, once local accountability improved as a result of various public health acts establishing the most important functions of municipalities in this regard, an increasing number of public measures in this realm began to take place (Szreter, 1988).[19]

A different strand of the literature does not concur with this view. Re-examining the English case, Aidt et al. (2010) posit that the relationship between public spending and the extension of the franchise during the 19th century had a U-shaped form. Their model implies that the rich favor public goods provision given that their benefits are proportional to capital endowments of the elite, while the middle class opposes paying higher taxes because they bore a large incidence of the property tax. More recently, Chapman (2022a) argues that this relationship has the opposite form (inverted-U shape), because costs were too high for the poor and the rich feared a high tax burden. While the divergent predictions in their theoretical models can be ascribed to the aforementioned assumptions about spending across the income spectrum, the latter model is underpinned by stronger empirical evidence. Chapman (2022a) relies on a more comprehensive sample of towns (150 instead of 55) with annual data. In addition, he replicates the analyses by Aidt et al. (2010) and shows that these are mostly driven by a sample biased towards large towns. In sum, it is clear that the link between spending and democratization is much weaker than previously thought in England.

Evidence from the United States supports the case for good institutions., Miller (2008) shows that the extension of suffrage rights for American women led to increases in local public health expenditures and Troesken (2015) argues that a state structure conducive to economic development had benefits for the deployment of expensive water systems by promoting the market for municipal debt.[20] For

[19] A different mechanism concerns the complementarity between infrastructural improvement and institutions in that property rights both empowers owners and imposes social obligations, such as connecting your property to the pipe or sewer network (Ashraf, Glaeser, & Ponzetto, 2016).

[20] The narrative of Troesken (2015) is, in fact, more nuanced. He posits that the preservation of economic liberty and a federalist approach hindered the adoption of coherent and rational public health measures. To be sure, policy decisions regarding, for instance, the functioning of financial markets are not ultimate (or long-run drivers) of sanitary spending. However, the institutional framework in which these decisions are developed and enforced plays a crucial role.

Germany, on the other hand, Brown (1988) finds that the rising income of industrialists, who had significant political power in Germany, and factory needs were key drivers of local water demands.[21] Therefore, self-interested elites could lead to sanitary reform, if this was in their interest. Becker and Hornung (2021) support this narrative by arguing that German industrialization displaced landowners in the three-class political franchise of local Prussian municipalities that led to more progressive politics, as industrial elites were more liberal than landowners (Krieger, 2022). In sum, the aims of those with greater political influence are essential in explaining decisions to fund infrastructures (Bogart, 2022).

In other world regions, colonial influence shaped the long-run evolution of public goods provision. In India, the British created differences in historical property rights by setting up different colonial revenue systems. Areas where this was transferred from cultivators to landlords perform worse in the 1980s than places where taxes were collected from peasants, despite the landlord system was abolished in the 1950s (Banerjee & Iyer, 2005). In Colombia, Acemoglu, García-Jimeno, and Robinson (2015) show that the historical presence of the Spanish colonial state influenced the long-run evolution of local state capacity, and this in turn explains aqueduct and sewerage coverage. For Africa, on the other hand, there is not a clear-cut 'legacy' or pattern. Frankema (2011) uncovers a large degree of variation across colonies between 1870 and 1940 in their capacity to levy taxes, health care spending and the number of civil employees in the medical and sanitation department.

Biogeography

This ultimate factor refers to the biological and geographic features of a given region, such as the availability of overground and underground water, characteristics of the soil (slope, porosity), weather features (temperatures, humidity) or the presence of disease vectors. Beginning with local geographic conditions, these determine the supply of sanitary infrastructures via their effect on construction and maintenance costs. The availability of abundant water, soil type and orography posed real constraints to municipalities that often struggled to find suitable and sufficient amounts of water in a context of rapid population growth. In Bombay and Singapore burying water mains – a practice imported by engineers from England to prevent freezing during cold months – soon became a problem after they severely rust in about two decades or less. The saline soil of Bombay caused widespread corrosion to such an extent that some parts of the pipe could be cut with a knife. In addition, the tropical sun and warm water promoted the growth of plants inside the water reservoir, which could not be regularly emptied for cleaning purposes (Broich, 2007, p. 358). While harnessing sufficient water for urban

[21] Similarly, Hassan (1985) argues that some industries (textile, chemical or paper) needed high-quality soft water, which incentivized English industrialists to support the construction waterworks in the face of decreasing water quality due to growing population density and pollution.

consumption was a viable enterprise in Bombay and Calcutta, the same did not apply to other parts of India such as the south, where a weaker monsoon and higher temperatures created greater fluctuations in water availability (T. Roy, 2021, p. 587). Geographic factors were also relevant in the United States. Alsan and Goldin (2019) provide econometric evidence on the link between the timing of water and waste disposal interventions in Massachusetts and geographic features, such as distance from the water reservoir and sewerage outlets.

Another mechanism linking biogeographic conditions and infrastructural improvements refers to the role of epidemics, and disease incidence in general, in increasing demand for clean water and sewerage. The economics intuition is that the social benefit of installing sanitary infrastructures might be higher in places where the survival and diffusion of germs and vectors is greater, as a result of climatic conditions (e.g. temperature, humidity or rainfall) or geography (e.g. elevation or presence of surface water). The environmental features of a region are rather stable, but their influence on the perceived benefit of installing waterworks may interact with factors that can vary rather quickly, such as migration and urbanization, that foster the diffusion of infectious diseases.

The historical literature often cites pestilence, and cholera in particular, as a driver of water and sanitation investments. Since the international spread of this disease in the 19th century, numerous outbreaks wreaked havoc among populations throughout the world potentially triggering political reaction and providing impetus for infrastructural improvements. The experience of Germany is illustrative. The cholera epidemic of 1866 has been put forward as a catalyst for sanitary reform because it generated momentum for public health experts, such as Max von Pettenkofer, to organize cholera conferences and organize associations and periodicals giving voice to the German sanitary movement that advocated ideas of sanitation and cleanliness (Weindling, 1994, p. 123). These reform organizations, in turn, prompted the liberal urban middle class to spend on waterworks because they had members and officials active in city councils (Hennock, 2000, pp. 279-280). Similar narratives supporting this hypothesis have been put forward in other countries, such as Austria, France, Italy, the United States, Australia or French Senegal (Frost, 2020, p. 20; Lenger, 2012, p. 150; Melosi, 2000, p. 77; Neundlinger, Gierlinger, Pollack, & Krausmann, 2014; Ngalamulume, 2007). While these arguments may have been compelling from a humanitarian point of view, the literature would benefit from additional evidence coming from quantitative studies examining the occurrence of an epidemic and subsequent urban reform, including why earlier epidemics might not have had the same effect.

Culture

The last ultimate determinant that I will elaborate on is culture, which consists of norms and beliefs held by individuals. These can refer to ideas and practices derived from tradition, religious doctrines

or intellectual movements that influence the demand for piped water and sewerage. This mechanism has not received much attention from economic historians, although a number of qualitative works indicate their importance in some settings. Mokyr and Stein (1996) argue that better medical knowledge led to increased demand for sanitary services by both households and policymakers during the 19th-century Europe due to, in part, the steady increase in human capital and the teaching of hygienic ideas in schools. For India, Harrison (1994) discusses that the establishment of waterworks were sometimes opposed by the community on cultural grounds. In one occasion in 1892, riots broke out after the construction of a new waterworks on the banks of the River Ganges. In addition, social and economic discrimination could lead to major inequalities hindering widespread access to clean water, as 'untouchables' were often not allowed to access water sources used by higher castes, such as the Brahmin (T. Roy, 2021).

Discrimination also shaped the diffusion of waterworks in the United States. Beach, Parman, and Saavedra (2022) note that more segregated cities constructed them earlier, but had lower subsequent coverage rates. They model this with city planners holding racial discriminatory beliefs against black households that promoted the limited provision of some neighborhoods to lower the costs of water provision. This, paradoxically, could have led to earlier implementation of waterworks in segregated cities, since within-city distribution costs would have been lower than in cities providing water to the whole population. As a result, typhoid fever mortality took longer to fade away in places where social and economic inequality was higher.

Cultural imitation and aspiration could be a positive force for installing waterworks. In Istanbul, the *alla franca* way of life was highly valued among the upper class in Istanbul that were eager to adopt Western technologies representing 'modernization' (Dinçkal, 2008). Consequently, the wealthier districts of the city were prioritized over a more equitable distribution during the initial years of centralized water provision. In Japan, the radical attitude change towards Western technology prompted by the Meiji Restoration paved the way for a number of engineering works that would be completed in subsequent decades. Engineers from various countries, such as the United Kingdom or the Netherlands, were hired by the Ministry of Interior to build the first generation of waterworks (Kosuge, 1981, p. 82).

Summing up

Ultimate determinants are crucial to understand inequalities in access to clean water and efficient sanitation. The literature has devoted substantial attention to the role of institutional contexts and political economy considerations, although these are not the only relevant factors. Cultural attitudes can be crucial in determining why urban inequalities persist and the relatively late arrival of modern

sanitation to major cities in some countries, such as Japan. In addition, the interaction of cities' biogeographic conditions with demographic processes may have generated some opportunities for changing a political equilibrium skewed towards the wealthy. This last has potential to account for between- and within-country diffusion patterns of waterworks and sewerage, given that biogeographic conditions vary widely throughout the world as well as within large and diverse countries, such as China or India.

6. Moving forward

This survey has attempted to shed light on the causes and consequences of the sanitary revolution that resulted in the establishment of waterworks and sewerage systems between ca. 1850-1940, by drawing on research from the fields of economic history, economics and history. It begins by presenting some basic patterns of waterworks and sewerage construction in different parts of the world. Three are worth mentioning. First, major cities throughout the world built these infrastructures at a (roughly) similar time between ca. 1850s-1890s. Second, there were large differences in their timing both within and between countries before ca. 1880; afterwards only municipalities in some (industrialized) countries converged with frontrunners. And third, the within-city diffusion of pipes and sewers was even more unequal between countries than the initial construction of waterworks and sewerage.

What were the health consequences of the new water and sanitation technologies? Evidence from a large number of countries point at positive effects, although somewhat lower than initially thought: estimates from comparable studies indicate that infant mortality declined between ca. 10 and 30 percent following their construction. In industrial settings, it seems that the effectiveness of waterworks was limited in the absence of sewerage systems, where their joint effect can explain between 20 and 25 percent of the fall in infant and overall mortality. More generally, we need a better understanding of local contexts to grasp the heterogeneous impact of these infrastructures, since they interacted with city-specific social, economic, demographic and technological aspects. Also, the economic history literature would profit in various ways from accumulating experiences from non-Western countries that began investing in waterworks and sewerage since the 1860s (see section 3). Consider the case of India, where access to cutting-edge British engineering knowledge let to the construction of various waterworks and sewerage systems during the colonial period. How effective were these in the face of frequent famines and devastating epidemics (e.g. cholera, plague and influenza)? Moreover, exploring the impact of piped water and sewers in a context of extreme poverty, exploitation and social and economic inequality is essential to understanding their effectiveness and accessibility. Similarly, the experience of some African cities during the first half of the 20th century can

shed light on the efficacy of public health interventions in an epidemiological context where vector-transmitted diseases, such as malaria or sleeping sickness, played an important role in health outcomes.

What explains the adoption patterns of water and sanitation technologies since ca. 1850? Despite the vast body of knowledge produced in the last decades, a satisfactory answer to this question cannot be provided yet. As a first approximation, I offer a framework that distinguishes between *proximate* and *ultimate* determinants with the aim of separating factors influencing the supply of inputs in the production process from others that are slow-moving and widely differ across countries. This highlights how the demand and supply of urban amenities can be shaped by a number of mechanisms related to institutions, such as the well-functioning of financial markets, democratization and colonial fiscal legacies; to biogeography, such as water availability and characteristics of the soil, and the incidence of infectious disease; and to culture, such as conflicting ideas about public health, social discrimination, cultural imitation.

This survey points at some concrete processes that shaped local political power and decision making that ultimately brought about sanitary investments. For instance, broad democratization was not a necessary condition for cities to invest in water and sanitation projects everywhere. The extension of franchise in England did not invariably result in greater public health spending; the highly-unequal political environment of German cities did not prevent them from becoming world leaders in sanitary services; and American elites used their ability to discriminate against their black counterparts to construct expensive waterworks from which they were excluded. In such contexts, it was in the interest of elites to support their provision, be it to promote their industrial business requiring clean water and a healthy labor force or to lower their construction by limited within-city coverage. In addition, these elites may have demanded clean water and more efficient waste disposal if they felt that their lives were at stake. The development of a culture of hygiene during the 19th century, ultimately underpinned by scientific medical advances, first spread among the elite and ultimately increased the perceived value of expensive public health investments. This issue was particularly salient during deadly epidemics, such as cholera, that were associated with filth and deprivation. The quantitative importance of this mechanism, however, is unclear and further research is needed to assess its importance in various contexts. In this regard, the literature would greatly benefit from non-Western experiences where epidemic outbreaks did not recede during the late 19th century.

These are just but a few examples of how economic and political mechanisms operate within broader institutional, cultural and biogeographic contexts that produce constraints and opportunities to invest in water and sanitation infrastructures. It is this interplay of factors that we should devote our efforts

to understand why so many citizens have gained access to safe water and sanitation, while many others continue to suffer from limited (or lack of) access to these basic rights.

References

Acemoglu, D., García-Jimeno, C., & Robinson, J. A. (2015). State Capacity and Economic Development: A Network Approach. *American Economic Review, 105*(8), 2364-2409.

Aidt, T. S., Daunton, M., & Dutta, J. (2010). The Retrenchment Hypothesis and the Extension of the Franchise in England and Wales. *The Economic Journal, 120*(547), 990-1020.

Aidt, T. S., Davenport, R. J., & Gray, F. (2023). New perspectives on the contribution of sanitary investments to mortality decline in English cities, 1845–1909. *The Economic History Review*.

Alsan, M., & Goldin, C. (2019). Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880-1920. *Journal of Political Economy, 127*(2), 586-638.

Anderson, D. M., Charles, K. K., & Rees, D. I. (2022). Re-Examining the Contribution of Public Health Efforts to the Decline in Urban Mortality. *American Economic Journal: Applied Economics, 14*(2), 126-157.

Anderson, D. M., Charles, K. K., Rees, D. I., & Wang, T. (2021). Water purification efforts and the black-white infant mortality gap, 1906–1938. *Journal of Urban Economics, 122*, 103329.

Anderson, D. M., Rees, D. I., & Wang, T. (2020). The phenomenon of summer diarrhea and its waning, 1910-1930. *Explorations in Economic History, 78*.

Anderson, L. (1984). Hard Choices: Supplying Water to New England Towns. *The Journal of Interdisciplinary History, 15*(2), 211-234.

Ashraf, N., Glaeser, E. L., & Ponzetto, G. A. M. (2016). Infrastructure, Incentives, and Institutions. *American Economic Review: Papers & Proceedings, 106*(5), 77-82.

Baker, A. C., Larcker, D. F., & Wang, C. C. Y. (2022). How much should we trust staggered difference-in-differences estimates? *Journal of Financial Economics, 144*(2), 370-395.

Baker, M. N. (1891). *The Manual of American Water-Works*. New York: Engineering News Press.

Bakker, G., Crafts, N. F. R., & Woltjer, P. J. (2019). The Sources of Growth in a Techonologically Progressive Economy: the United States, 1899-1941. *The Economic Journal, 129*(622), 2267-2294.

Banerjee, A., & Iyer, L. (2005). History, Institutions, and Economic Performance: The Legacy of Colonial Land Tenure Systems in India. *The American Economic Review, 95*(4), 1190-1213.

Banerjee, A., Iyer, L., & Somanathan, R. (2006). Public action for public goods. In T. P. Schultz & J. A. Strauss (Eds.), *Handbook of Development Economics* (Vol. 4): Elsevier.

Beach, B. (2022). Water infrastructure and health in U.S. cities. *Regional Science and Urban Economics, 94*, Article 103674.

Beach, B., Ferrie, J. P., Saavedra, M., & Troesken, W. (2016). Typhoid Fever, Water Quality, and Human Capital Formation. *The Journal of Economic History, 76*(1), 41-75.

Beach, B., Parman, J., & Saavedra, M. H. (2022). Segregation and the Initial Provision of Water in the United States. *AEA Papers and Proceedings, 112*, 193-198.

Beach, B., Troesken, W., & Tynan, N. (2016). *Who should own and control urban water systems? Historical evidence from England and Wales*. NBER Working Paper No. 22553. Retrieved from the National Bureau of Economic Research website: https://www.nber.org/papers/w22553.pdf [accessed on 06-07-2020].

Becker, S. O., & Hornung, E. (2021). The Political Economy of the Prussian Three-class Franchise. *The Journal of Economic History, 80*(4), 1143-1188.

Bennet, R. J. (2012). *Urban population database, 1801-1911*.

Bhalotra, S. R., Diaz-Cayeros, A., Miller, G., Miranda, A., & Venkataramani, A. S. (2021). Urban Water Disinfection and Mortality Decline in Lower-Income Countries. *American Economic Journal: Economic Policy, 13*(4), 490-520.

Bogart, D. (2022). Infrastructure and institutions: Lessons from history. *Regional Science and Urban Economics, 94*, Article 103626.

Broich, J. (2007). Engineering the Empire: British Water Supply Systems and Colonial Societies, 1850–1900. *Journal of British Studies, 46*(2), 346-365.

Brown, J. C. (1988). Coping with Crisis? The Diffusion of Waterworks in Late Nineteenth-Century German Towns. *The Journal of Economic History, 48*(2), 307-318.

Brown, J. C. (2000a). Economics and Infant Mortality Decline in German towns, 1889-1912: Household Behaviour and Public Intervention. In S. Sheard & H. Power (Eds.), *Body and City: Histories of Urban Public Health* (pp. 166-193). Aldershot: Ashgate.

Brown, J. C. (2000b). Wer bezahlt die hygienisch saubere Stadt? Finanzielle Aspekte der sanitären Reformen in England, USA und Deutschland um 1910. In J. Vögele & W. Woelk (Eds.), *Stadt, Krankheit und Tod. Geschichte der städtischen Gesundheitsverhältnisse während der Epidemiologischen Transition (vom 18. bis ins frühe Jahrhundert)*. Berlin: Duncker & Humblot.

Buchanan, R. A. (1986). The Diaspora of British Engineering. *Technology and Culture, 27*(3), 501-524.

Chadwick, E. (1842). *Report from the Poor law Commissioners on an Inquiry into the Sanitary Conditions of the Labouring Population of Great Britain*. London: W. Clowes and sons.

Chapman, J. (2019). The contribution of infrastructure investment to Britain's urban mortality decline, 1861-1900. *The Economic History Review, 72*(1), 233-259.

Chapman, J. (2022a). Gradual Franchise Extensions and Government Spending in Nineteenth-Century England. *Journal of Politics, XXXX*(XXXX), XXXX.

Chapman, J. (2022b). Interest Rates, Sanitation Infrastructure, and Mortality Decline in Nineteenth-Century England and Wales. *The Journal of Economic History, 82*(1), 175-210.

Clay, K. (2023). Energy and the Environment in Economic History. In C. Diebolt & M. J. Haupert (Eds.), *Handbook of Cliometrics (3rd. edition)*: Springer.

Clay, K., Troesken, W., & Haines, M. R. (2014). Lead and Mortality. *Review of Economics and Statistics, 96*(3), 458-470.

Coleman, W. (1982). *Death Is A Social Disease*. Wisconsin: University of Wisconsin Press.

Costa, D. L. (2015). Health and the Economy in the United States from 1750 to the Present. *Journal of Economic Literature, 53*(3), 503-570.

Cutler, D., Deaton, A., & Lleras-Muney, A. (2006). The Determinants of Mortality. *Journal of Economic Perspectives, 20*(3), 97-120.

Cutler, D., & Miller, G. (2005). The role of public health improvements in health advances: The twentieth-century United States. *Demography, 42*(1), 1-22.

Cutler, D., & Miller, G. (2006). Water, Water Everywhere: Municipal Finance and Water Supply in American Cities. In E. L. Glaeser & C. Goldin (Eds.), *Corruption and Reform: Lessons from America's Economic History* (pp. 153-183). Chicago: University of Chicago Press

Davenport, R. J., Satchell, M., & Shaw-Taylor, L. M. (2019). Cholera as a 'sanitary test' of British cities, 1831–1866. *The History of the Family, 24*(2), 404-438.

de Looper, M. W., Booth, H., & Baffour, B. (2019). Sanitary improvement and mortality decline in Sydney, New South Wales, 1857–1906: drinking water and dunnies as determinants. *The History of the Family, 24*(2), 227-248.

Deaton, A. (2013). *The Great Escape: Health, Wealth, and the Origins of Inequality*. Princeton: Princeton University Press.

Deutschen Vereins von Gas- und Wasserfachmännern. (1870). *Journal für Gasbeleuchtung und verwandte Beleuchtungsarten sowie für Wasserversorgung*. Munich: R. Oldenbourg.

Dinçkal, N. (2008). Reluctant Modernization: The Cultural Dynamics of Water Supply in Istanbul, 1885-1950. *Technology and Culture, 49*(3), 675-700.

Easterlin, R. A. (1999). How beneficent is the market? A look at the modern history of mortality. *European Review of Economic History, 3*(3), 257-294.

Evans, R. J. (1987). *Death in Hamburg: Society and Politics in the Cholera Years, 1830-1910*. Oxford Clarendon Press.

Feigenbaum, J. J., & Muller, C. (2016). Lead exposure and violent crime in the early twentieth century. *Explorations in Economic History, 62*, 51-86.

Feinstein, C. H. (1972). *National Income, expenditure and output of the United Kingdom, 1855-1965*. Cambridge: Cambridge University Press.

Felacio Jimenez, L. C. (2017). *El Acueducto de Bogotá: Procesos de diferenciación social a partir del acceso al servicio público de agua, 1911-1929*. Bogotá: Secretaría General - Imprenta Distrital.
Ferrie, J. P., & Troesken, W. (2008). Water and Chicago's mortality transition, 1850-1925. *Explorations in Economic History, 45*(1), 1-16.
Floris, J., & Staub, K. (2019). Water, sanitation and mortality in Swiss towns in the context of urban renewal in the late nineteenth century. *The History of the Family, 24*(2), 249-276.
Floud, R., Fogel, R. W., Harris, B., & Hong, S. C. (2011). *The Changing body: Health, Nutrition, and Human Development in the Western World since 1700*. Cambridge: Cambridge University Press.
Fogel, R. W. (1994). Economic Growth, Population Theory and Physiology: The Bearing of Long-Term Process on the Making of Economic Policy. *American Economic Review, 84*(3), 369-395.
Fogel, R. W. (2004). *The Escape from Hunger and Premature Death, 1700-2100. Europe, America, and the Third World*. Cambridge: Cambridge University Press.
Frankema, E. (2011). Colonial taxation and government spending in British Africa, 1880–1940: Maximizing revenue or minimizing effort? *Explorations in Economic History, 48*(1), 136-149.
Frost, L. (2020). Water Technology and the Urban Environment: Water, Sewerage, and Disease in San Francisco and Melbourne before 1920. *Journal of Urban History, 46*(1), 15-32.
Fuentes-Vásquez, M. J., & España-Eljaiek, I. (2022). Coffee tastes bitter: education and the coffee economy in Colombia in the late nineteenth and early twentieth centuries. *European Review of Economic History*.
Gallardo-Albarrán, D. (2018). Health and economic development since 1900. *Economics & Human Biology, 31*, 228-237.
Gallardo-Albarrán, D. (2019). Missed opportunities? Human welfare in Western Europe and the United States, 1913-1950. *Explorations in Economic History, 72*, 57-73.
Gallardo-Albarrán, D. (2020). Sanitary infrastructures and the decline of mortality in Germany, 1877-1913. *The Economic History Review, 73*(3), 730-757.
Gallardo-Albarrán, D. (2023). Capital, Productivity, and Human Welfare since 1870. In C. Diebolt & M. Haupert (Eds.), *Handbook of Cliometrics (Third Edition)*: Springer.
Gallardo-Albarrán, D., & Inklaar, R. (2021). The role of capital and productivity in accounting for income differences since 1913. *Journal of Economic Surveys, 35*(3), 952-974.
Geruso, M., & Spears, D. (2018). Neighborhood Sanitation and Infant Mortality. *American Economic Journal: Applied Economics, 10*(2), 125-162.
Goode, S. W. (1916). *Municipal Calcutta: Its Institutions in Their Origin and Growth*. Edinburg: Corporation of Calcutta.
Grahn, E. (1898-1902). *Die städtische Wasserversorgung im Deutschen Reiche sowie in einigen Nachbarländern*. Munich and Leipzig: R. Oldenbourg.
Grahn, E. (1904). Die städtischen Wasserwerke. In R. Wuttke (Ed.), *Die deutschen Städte. Geschildert nach dem Ergebnissen der ersten deutschen Städteausstellung zu Dresden 1903* (pp. 301-344). Leipzig: Friedrich Brandstetter.
Guillerme, A. (1988). The Genesis of Water Supply, Distribution, and Sewerage Systems in France, 1800-1850. In J. A. Tarr & G. Dupuy (Eds.), *Technology and the rise of the networked city in Europe and America* (pp. 91-115). Philadelphia: Temple University Press.
Hardy, A. (1991). Parish pump to private pipes: London's water supply in the nineteenth century. *Medical History, 35*(S11), 76-93.
Harris, B., & Hinde, A. (2019). Sanitary investment and the decline of urban mortality in England and Wales, 1817–1914. *The History of the Family, 24*(2), 339-376.
Harrison, M. (1994). *Public Health in British India: Anglo-Indian Preventive Medicine 1859-1914*. Cambridge: Cambridge University Press.
Hassan, J. A. (1985). The Growth and Impact of the British Water Industry in the Nineteenth Century. *The Economic History Review, 38*(4), 531-547.
Helgertz, J., & Önnerfors, M. (2019). Public water and sewerage investments and the urban mortality decline in Sweden 1875–1930. *The History of the Family, 24*(2), 307-338.

Hennock, E. P. (2000). The urban sanitary movement in England and Germany, 1838-1914: a comparison. *Continuity and Change, 15*(2), 269-296.
Hoehn-Velasco, L. (2018). Explaining declines in US rural mortality, 1910–1933: The role of county health departments. *Explorations in Economic History, 70*, 42-72.
Inoue, T., & Ogasawara, K. (2020). Chain effects of clean water: The Mills–Reincke phenomenon in early 20th-century Japan. *Economics & Human Biology, 36*.
Jaadla, H., & Puur, A. (2016). The impact of water supply and sanitation on infant mortality: Individual-level evidence from Tartu, Estonia, 1897–1900. *Population Studies, 70*(2), 163-179.
Jaramillo-Echeverri, J., Meisel-Roca, A., & Teresa Ramírez-Giraldo, M. (2019). More than 100 years of improvements in living standards: the case of Colombia. *Cliometrica, 13*(3), 323-366.
Juuti, P. S., Katko, T. S., & Vuorinen, H. S. (2007). *Environmental History of Water*. London: IWA.
Kaiserliches Gesundheitsamt. (1904). *Statistische Zusammenstellung der Wasserversorgung und Beseitigung der Abfallstoffe in deutschen Orten mit 15000 und mehr Einwohnern: April 1904*. Berlin: Springer.
Kappner, K. (2023). "Cholera Forcing" and the Urban Water Infrastructure: Lessons from Historical Berlin In L. Frost & M. Shanahan (Eds.), *Managing Water: Lessons from History*. Pennsylvania: Pennsylvania University Press.
Kesztenbaum, L., & Rosenthal, J.-L. (2017). Sewers' diffusion and the decline of mortality: The case of Paris, 1880-1914. *Journal of Urban Economics, 98*, 174-186.
Kosuge, N. (1981). Development of waterworks in Japan. *Developing Economies, 19*(1), 69-94.
Kremer, M., Leino, J., Miguel, E., & Zwane, A. P. (2011). Spring Cleaning: Rural Water Impacts, Valuation, and Property Rights Institutions. *The Quarterly Journal of Economics, 126*(1), 145-205.
Krieger, T. (2022). *Elites and Health Infrastructure Improvements in Industrializing Regimes*. CESifo Working Paper No. 9808. Retrieved from: https://www.cesifo.org/DocDL/cesifo1_wp9808.pdf [accessed on 13-01-2022].
Lenger, F. (2012). *European Cities in the Modern Era, 1850-1914*. Leiden and Boston: Brill.
Local Government Board. (1913). *42nd Annual Report of the Local Government Board for 1912-1913* (Vol. 3).
Mäki, H. (2010). Comparing developments in water supply, sanitation and environmental health in four South African cities. *Historia 55*(1), 90-109.
March, H. (2015). Taming, controlling and metabolizing flows: Water and the urbanization process of Barcelona and Madrid (1850–2012). *European Urban and Regional Studies, 22*(4), 350-367.
McKeown, T. (1976). *The Modern Rise of Population*. New York: Academic Press.
Melosi, M. V. (2000). *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. Baltimore: Johns Hopkins University Press.
Miller, G. (2008). Women's Suffrage, Political Responsiveness, and Child Survival in American History. *The Quarterly Journal of Economics, 123*(3), 1287–1327.
Millward, R. (2000). The political economy of urban utilities. In P. Clark (Ed.), *The Cambridge Urban History of Britain* (Vol. 3). Cambridge: Cambridge University Press.
Mohajeri, S. (2005). *100 Jahre Berliner Wasserversorgung und Abwasserentsorgung 1840-1940*. Stuttgart: Franz Steiner Verlag.
Mokyr, J., & Stein, R. (1996). Science, Health, and Household Technology: The Effect of the Pasteur Revolution on Consumer Demand. In T. F. Bresnahan & R. J. Gordon (Eds.), *The Economics of New Goods* (pp. 143-206). Chicago: University of Chicago Press.
Morabia, A. (2007). Epidemiologic Interactions, Complexity, and the Lonesome Death of Max von Pettenkofer. *American Journal of Epidemiology, 166*(11), 1233-1238.
Moreno Méndez, J. O. (2020). Los retos del acceso a agua potable y saneamiento básico de las zonas rurales en Colombia. *Revista De Ingeniería, 49*(1), 28-37.
Muñoz, M. (2019). Imaginarios y tránsito socio-técnico hacia un régimen de saneamiento en Ciudad de Buenos Aires y Santiago de Chile (1860-1930). In R. Casas & T. Pérez-Bustos (Eds.), *Ciencia,*

tecnología y sociedad en América Latina : la mirada de las nuevas generaciones. Buenos Aires: Asociación Latinoamericana de Estudios Sociales de la Ciencia y la Tecnologías.

Neundlinger, M., Gierlinger, S., Pollack, G., & Krausmann, F. (2014). An Environmental History of the Viennese Sanitation System - From Roman to Modern Times. In T. Tvedt & T. Oestigaard (Eds.), *A History of Water. Series III.* (Vol. 1: Water and Urbanization). London and New York: I. B. Tauris.

Ngalamulume, K. J. (2007). Coping with Disease in the French Empire: The Provision of Waterworks in Saint-Louis-du-Senegal, 1860–1914. In P. S. Juuti, T. S. Katko, & H. S. Vuorinen (Eds.), *Environmental History of Water*. London: IWA.

Ogasawara, K., & Matsushita, Y. (2019). Heterogeneous treatment effects of safe water on infectious disease: Do meteorological factors matter? *Cliometrica, 13*(1), 55-82.

Ogasawara, K., Shirota, S., & Kobayashi, G. (2018). Public health improvements and mortality in interwar Tokyo: a Bayesian disease mapping approach. *Cliometrica, 12*(1), 1-31.

Olson, M. (1965). *The Logic of Collective Action*. Cambridge, MA: Harvard University Press.

Peltola, J., & Saaritsa, S. (2019). Later, smaller, better? Water infrastructure and infant mortality in Finnish cities and towns, 1870–1938. *The History of the Family, 24*(2), 277-306.

Peltola, J., Saaritsa, S., & Mikkola, H. (2024). Can't Boil, Won't Boil: Material Inequality, Information, and Disease Avoidance during a Typhoid Epidemic in Tampere, Finland, in 1916. *Social Science History*.

Pinto Crespo, V., Gili Ruiz, R., & Velasco Medina, F. (2015). *Proyecto de Investigación. Historia del saneamiento de Madrid*. Madrid: Universidad Autónoma de Madrid.

Porter, D. (1999). *Health, Civilization and the State: A History of Public Health from Ancient to Modern Times*. London: Routledge.

Raftakis, M. (2023). Urban mortality in Greece: Hermoupolis(1859–1940). *The Economic History Review*.

Reulecke, J. (1985). *Geschichte der Urbanisierung in Deutschland*. Frankfurt am Main: Suhrkamp.

Rodrik, D. (2003). Introduction: What Do We Learn from the Country Narratives? In D. Rodrik (Ed.), *In Search of Prosperity: Analytic Narratives on Economic Growth* (pp. 1-19). Princeton: Princeton University Press.

Rosen, C. M. (1986). Infrastructural Improvement in Nineteenth-Century Cities. A Conceptual Framework and Cases. *Journal of Urban History, 12*(3), 211-256.

Rosen, G. (1958/1993). *The History of Public Health (Expanded edition)*. Baltimore and London: The Johns Hopkins University Press (Original work published in 1958).

Roy, C., Sati, V. P., Biswas, A., & Kumar, S. (2023). Status of drinking water, sanitation facilities, and hygiene in West Bengal: evidence from the National Family Health Survey of India (NFHS), 2019–2021. *Journal of Water, Sanitation and Hygiene for Development, 13*(1), 50-62.

Roy, T. (2021). Water, Climate, and Economy in India from 1880 to the Present. *Journal of Interdisciplinary History, 51*(4), 565–594.

Sánchez Gómez, P. J. (2016). *Historia del abastecimiento moderno de aguas de Sevilla: la presencia inglesa en el siglo XIX (1882 1900)*. Sevilla: Empresa Metropolitana de Abastecimiento y Saneamiento de Aguas de Sevilla S.A.

Szreter, S. (1988). The Importance of Social Intervention in Britain's Mortality Decline c. 1850-1914: a Re-Interpretration of the Role of Public Health. *Social History of Medicine, 1*(1), 1-38.

Troesken, W. (1999). Typhoid Rates and the Public Acquisition of Private Waterworks, 1880-1920. *The Journal of Economic History, 59*(4), 927-948.

Troesken, W. (2004). *Water, Race, and Disease*. Cambridge: MIT Press.

Troesken, W. (2008). *The Great Lead Water Pipe Disaster*. Cambridge: MIT Press.

Troesken, W. (2015). *The Pox of Liberty: How the Constitution Left Americans Rich, Free, and Prone to Infection*. Chicago: Chicago University Press.

Troesken, W., Tynan, N., & Yang, Y. A. (2021). What are the health benefits of a constant water supply? Evidence from London, 1860–1910. *Explorations in Economic History, 81*, 1-26.

U.S. Bureau of Census. (1913). *General Statistics of Cities: 1909*. Washington: Government Printing Office.

United Nations. (2022). *The Sustainable Development Goals Report*. New York: United Nations.

Vakgroep Waterleidingbedrijven. (1948). *Beknopt Statistisch Overzicht der Waterleidingen in Nederland over de jaren 1940 t/m 1945*. Amsterdam: J. H. de Bussy.

van Poppel, F., & van der Heijden, C. (1997). The effects of water supply on infant and childhood mortality: a review of historical evidence. *Health Transition Review, 7*(2), 113-148.

Vereeniging voor waterledingsbelangen in Nederland. (1917). *Statistiek overzicht der waterleidingen in Nederland over het jaar 1915*. Utrecht: J. van Boekhoven.

Weindling, P. (1994). Public Health in Germany. In D. Porter (Ed.), *The history of public health and the modern state* (pp. 119-131). Amsterdam: Editions Rodopi.

Zwane, A. P., & Kremer, M. (2007). What Works in Fighting Diarrheal Diseases in Developing Countries? A Critical Review. *The World Bank Research Observer, 22*(1), 1–24.

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