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Mortality Decline and Sanitation in 20th Century Bengal: A quantitative assessment of the impact of waterworks, drainage, and sewerage

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Abstract

The 20th century (post-1920) marked a decrease in the frequency of epidemics, disease-related deaths, and cholera deaths in South Asia. Studies of other regions have shown the importance of clean water provision and waste disposal systems in tackling waterborne diseases. I assess this hypothesis in relation to British-India, using Bengal as a case study, by estimating the share of cholera mortality decline due to progressive investments in major waterwork, drainage and sewerage schemes in towns across 20 districts. Firstly, my results show that increasing investment in waterworks by 10 percentage points reduced cholera deaths per mille by 0.003. However, the results show no significant effect of investments in drainage and sewerage on cholera death rates. I then extend the study of the effects of waterworks by comparing changes in cholera deaths between towns which received investment and towns which did not. My difference-in-differences estimation shows that in towns where waterworks were developed, average change in cholera deaths decreased by 37.42 more than it would have had investment not occurred. These findings support that there is a connection between clean water provision and waterborne disease mitigation, as well as the significance of colonial sanitary investments in preventing disease mortalities in India.

1. Introduction

1.1 India's mortality decline in the 20th century

Between 1881 and 1920, India suffered from a crisis in mortality, as millions of lives perished in the wake of terrible epidemics. Disease-related deaths had advanced from around 40 per mille (per 1000 citizens) in the 1880s to about 50 per mille by the 1910s.[1] Estimates of the average death rate for this entire period was 37.1 per mille, corresponding with a life expectancy of 27.7 for both sexes.[2]

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[1] Ira Klein. "Death in India, 1871-1921." *The Journal of Asian Studies* 32, no. 4 (1973): 639–59. https://doi.org/10.2307/2052814. 639

[2] Christophe Z. Guilmoto. "Towards a new demographic equilibrium: The interception of demographic transition in south India." *The Indian Economic & Social History Review* 29, no. 3 (1992): 247-89. https://doi-org.gate3.library.lse.ac.uk/10.1177/001946469202900301. 252

However, these trends reversed in the 1920s. By 1921, death rates per mille had finally dropped below 1880 levels, and the years which followed generally saw a decline in deaths and increase in life expectancy. From 42-50 per mille in the decade 1911-1921, the death rate fell to 25 per mille in 1941-1951.[3]

Scholars have long debated on the causes for India's mortality transition. It is challenging to pinpoint the precise factors for this trend reversal, as the period was characterized by a wealth of public initiatives, technical advancements, scientific breakthroughs, and by improved economic organization and infrastructure. But it is mostly agreed upon that declines in disease prevalence and improved living standards were the most significant indicators of mortality decline. The traditional hypothesis follows the Malthusian tradition, which argues that Britain was unable to revolutionize standards of living in India due the "rising flood of human beings".[4] Historians of this tradition argue that the fall in deaths in the 20th century represented natural checks on overpopulation and crowding which had hitherto increased the spread of disease. According to Knowles, mortality decline represented a natural return to normalcy after a period of cataclysms.[5] Another hypothesis refers to increased levels of biological resistance to diseases. Klein suggests that improved immunological responses due to inoculations reduced epidemic frequency and disease prevalence. McKeown shows through his analysis of Britain that rising living standards increased the nutritional status of man, which helped them develop greater biological resistance to diseases.[6] Guha presents an extensive study which rejects claims towards immunological resilience, evidencing climactic and meteorological factors as greater causes for the period's mortality decline.[7] Roy hypothesizes that relative absence of famines in the 20th century compared with

[3] Klein, *Death in India*, 640
[4] Ibid. 640
[5] L.C.A. Knowles. *Economic Development of the British Overseas Empire* (London: Routledge, 1924-36), 351-52; Reginald Coupland. *India: A Restatement* (London: Oxford University Press, 1945), pp. 52-62; Vera Anstey. *The Economic Development on India* (London: Longmans, Green & Company, 1929), 474; Phillip Woodruff. *The Men Who Ruled India* (London: J Cape, 1954), 109.
[6] Thomas McKeown. The Modern Rise of Population (London: Edward Arnold, 1976), 128-9
[7] Sumit Guha. "Mortality decline in early twentieth century India: A preliminary enquiry." *The Indian Economic & Social History Review* 28, no. 4 (1991): 371-391. https://doi.org/10.1177/001946469102800402. 387

the previous century was the primary reason for the fall in deaths, and that one of the features of famine resistance was improvements in public health and sanitary intervention.[8] By 1900, thanks to better scientific understanding of disease and germ theory, and the development of precise instruments and technologies for treatment, medical and sanitary intervention became more common and effective. Doctors and sanitary commissioners who had hitherto disagreed over the nature of diseases had finally come to consensus, allowing more precise measures to be taken for diseases like cholera, fever, and malaria.[9]

There are varying views on the role of colonialism in India. Some assert that colonialism was responsible for the high death rates, famines, and poor disease management in India. Conversely, others argue that British institutions facilitated medical and engineering advancements, leading to improvements in sanitation standards. Despite the application of European technologies and techniques, failures to contain diseases were exacerbated by factors beyond administrative control such as overpopulation, cultural backwardness, and geographical and climactic pressures. The conflict over colonial impact on India's mortality dynamics, and wider concerns over the cause for India's mortality rates lie outside my focus for this paper, but I will attempt to supplement the debate in some ways, by looking into the effects of specific policies under the colonial regime which directly sought to prevent disease in India.

1.2 Focus of research

The variety in diagnoses amongst current historians of mortality decline reiterates that the story of epidemiological transition varied greatly between and within regions. No one hypothesis can accurately explain the reasons for mortality decline for the entire subcontinent. To precisely understand the effects of these factors, it is necessary to examine one of them closely. The historical and contemporary studies of public health factors show global precedent for the

[8] Tirthankar Roy, "End of Famine." in *How British Rule Changed India's Economy: The Paradox of the Raj*, ed. Tirthankar Roy (London: Springer International Publishing AG, 2019), 111-2
[9] David Arnold. "Cholera and Colonialism in British India." *Past & Present*, no. 113 (1986): 118–51. http://www.jstor.org/stable/650982. 145

importance of sanitary reform.[10] Based on these observations, I will let other hypotheses be examined for further research, and rather evaluate the significance of sanitary reform and its effect on Indian health and wellbeing.

While my research aims to contribute to the wider debate on colonialism and wellbeing in India, there are limitations to extent my empirical results will demonstrate whether India was strictly better or worse off because of colonialism. To make such a claim, we would need to evaluate the counterfactual (being the absence of colonialism), which is not possible. It would thus be an incomplete conclusion to suggest that an improvement in Indian public health because of colonial intervention meant colonialism was good for India, as this assumes that colonialism was a necessary factor for public health improvements. Even if this is the case, this cannot be tested without considering the counterfactual. Therefore, my findings are not to be taken as a verdict on British colonial institutions, but rather, a demonstration of the mechanism between colonial public health initiatives and death occurrence. This will not only supplement further debate on colonialism in India but will directly contribute to the existing medical literature on sanitation by providing a historical account of the sanitary revolution in South Asia, and the connection between clean water and waste disposal, and disease mortality.

1.3 The Sanitary revolution and waterborne diseases in India

The end of the 19th century marked a revolution in hygienist ideas and the standardization of medical techniques in Europe, which progressively spread to their colonies. As societies adopted the principles of the germ theory of disease following the discoveries of Pasteur and Koch, there was a vast movement in public health initiatives towards clean water provision and waste disposal, mainly through the development of filtered water supplies and drainage and sewer systems, which grew rapidly.[11] There is great precedent for the causal

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[10] Arnold, *Cholera and Colonialism in British India*, 124

[11] Howard D. Kramer. "The Germ Theory and the Early Public Health Program in the United States." *Bulletin of the History of Medicine* 22, no. 3 (1948): 233–47. http://www.jstor.org/stable/44442191. 238

relationship between public health investment and death rates, with contemporary as well as historical studies of different regions around the world indicating the significance of medical and sanitary reforms in inducing mortality reversals. For instance, major cities in the United States experienced sharp declines in waterborne diseases following the implementation of clean water technologies and filtration systems.[12] Also, death rates from waterborne and food-borne diseases plummeted after 1911 in England and Wales following major improvements in hygiene, through water purification, waste disposal, refuse removal, and several other sanitary practices.[13] In the case of India, the main city of Bengal, Calcutta, experienced a dramatic drop in deaths from disease, especially cholera, following the opening of a new centralized sewerage system in 1865, and filtered water supply in 1869.[14] Sanitary intervention to mitigate diseases was a significant feature of 20th century economic development. The period saw a vast increase in medical and sanitary awareness, and the development of new techniques to regulate waste disposal and ensure the provision of clean water.

Moreover, death tolls from waterborne diseases were highly likely to respond strongly to improvements in sanitation and water quality, especially in India, where water sources were for a long time unregulated and uncleansed. Overtime, natural water sources developed a myriad of microbial species and pathogens. Also, underdeveloped irrigation and canal systems would frequently fail to control excess water creating stagnant pools which became cesspits for waterborne contagions. In addition to harmful microbes, natural and surface waters were prone to fecal contamination due to the absence of proper drainage and sewerage. Fecal contamination of water is globally recognized as one of the leading causes of waterborne diseases. The potential of drinking water to

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[12] David Cutler and Grant Miller. “The role of public health improvements in health advances: The twentieth-century United States.” *Demography* 42, 1–22 (2005). https://doi.org/10.1353/dem.2005.0002. 3

[13] Thomas McKeown, R. G. Record, and R. D. Turner. “An Interpretation of the Decline of Mortality in England and Wales during the Twentieth Century.” Population Studies 29, no. 3 (1975): 391–422. https://doi.org/10.2307/2173935. 391-2

[14] Arnold, *Cholera and Colonialism in British India*, 124

transport microbial pathogens to great numbers of people, causing subsequent illness and deaths, is well documented in countries at all levels of economic development.[15] It wasn't however until the 20th century when the state increased their focus on waterborne disease prevention and significantly invested in waterworks and waste disposal systems. Analyzing these investments closely, and the subsequent rate of deaths by waterborne diseases will reveal whether India's mortality decline can be explained by sanitary reform.

Finally, a study by the World Health Organization reinforces the importance of investing in sanitation and clean water. Hutton's tests on public health investment at the global level show that investments in improving sanitation, access to clean water, and sewerage systems are cost-beneficial, and have significant effects on the incidence of waterborne diseases like cholera and typhoid. The WHO recommends further investigation in regional case studies as a follow up to Hutton's global analysis of public health investment to verify whether the general story holds under different region-specific conditions.[16] My study will build upon this by providing a historical account of sanitary investment in South Asia, and its effects on deaths tolls from waterborne diseases.

1.4 Bengal as a case study

To analyze and understand the mechanisms by which colonial sanitary projects helped disease prevention, I will be focusing on the province of Bengal. British-India is too vast a region for there to be any one colony-wide story for mortality transition. Epidemiological patterns in different provinces, divisions, and districts were affected by numerous different factors, and a nationwide outlook of public health and the effects of colonial projects in disease prevalence in India risks misjudging the significance of certain localized projects. Also, each province

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[15] Nwabor Ozioma Forstinus et al. "Water and Waterborne diseases: A Review." International Journal of Tropical Disease and Health 12, no. 4 (2016): 1-14. https://doi.org/10.9734/IJTDH/2016/21895. 2

[16] Guy Hutton and Laurence Haller. "Evaluation of the Costs and Benefits of Water and Sanitation Improvements at the Global Level." *Water, Sanitation, and Health Protection of the Human Environment* (Geneva: World Health Organisation, 2004), 3, 39

in India had their own sanitary department, and policies and projects varied widely between them. This suggests that while India as a whole experienced a transition in mortality, the story of mortality between provinces would have been different, requiring investigation into each of them.[17] Also, Bengal has a large enough population, making up one fifth on India's population in the early 20th century, to have significance in producing a worthwhile account of India's mortality transition.[18] Moreover, for the period after 1921, Bengal was largely free from major epidemics and famines (until 1943), allowing us to examine the effects of public health investments without the interference of exogenous shocks which would inflate deaths. One exception to Bengal's mortality story was the city of Calcutta, where sanitary improvements had far exceeded the levels of most cities, towns, and rural areas in Bengal. To truly understand the weight of colonial intervention in sanitation for the entire province, I will exclude Calcutta from my analyses, as advancements made in this city are not going to be representative of the overall effectiveness of sanitary schemes. Though singling out one province may not be sufficient in detailing the whole story of India's epidemiological transition, Bengal is an appropriate and necessary case study for understanding India's mortality decline after 1921.

Table 1 presents the changes in the province's death rate per mille as well as deaths by major diseases for periods between 1906 and 1941. The data for Bengal corresponds to the general story of India's mortality during this period, as we see a steady decline in total death rates. The average of total mortality between 1936 and 1941 is 14% less than the average of total mortality recorded between 1906 and 1910. Mortalities from communicable diseases like cholera, plague, and fever also demonstrate a decline between periods. Whereas deaths from respiratory diseases show an increase between periods. This suggests that

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[17] Muhammed Umair Mushtaq. "Public Health in British India: A Brief Account of the History of Medical Services and Disease Prevention in Colonial India." Indian J Community Med. 34, no. 1 (2009): 6-14. https://doi.org/10.4103/0970-0218.45369. 8

[18] Edward Albert Gait, *Census of India, 1911*, (Calcutta: Superintendent Government Printing, India, 1913), Subsidiary Table II, 49

movement of environmental contagions, like cholera, smallpox, and fever where responsible for the change in total deaths rather than chronic diseases.

Table 1. Morality and Mortality from major diseases (per 1000) in Bengal averaged for periods between 1906 and 1941

Period	Total	Cholera	Smallpox	Plague	Fever	Dysentery and Diarrhoea	Respiratory Disease	All other causes
1906-1910	35.21	3.51	0.55	0.86	22.07	0.97	0.29	6.24
1911-1915	34.53	2.21	0.28	0.44	21.94	0.73	0.27	5.19
1916-1920	32.94	1.67	0.44	0.0045	23.03	0.56	0.38	4.14
1921-1925	31.10	1.10	0.19	0.00138	19.98	0.50	0.62	3.52
1926-1930	31.31	1.93	0.60	0.000024	16.22	0.68	0.90	3.50
1931-1935	31.25	1.01	0.19	0.000024	14.84	0.94	1.48	3.64
1936-1941	30.19	0.94	0.37	0.00008	14.93	1.09	1.82	4.30

Note: all rates are 'rate per 1000 citizens' ('per mille'). Mortalities have been averaged for each 5-year period between 1906 and 1941.
Sources: *Annual Report of the Sanitary Commissioner for Bengal (1906 to 1928), Bengal Public Health Report (1929 to 1941)*

1.5 Research question and structure of the paper

The aim of this paper is to assess the share of mortality decline in Bengal due to improvements in sanitary infrastructure by focusing on a specific channel: the impact of capital investments in major waterworks, drainage, and sewerage systems on the cholera death rate. Cholera is an interesting and appropriate disease to analyze for 3 reasons. Firstly, whilst cholera was rife in the beginning of the twentieth century, it's prevalence and epidemicity had significantly fallen by the 1930s and 40s. Between the first five-year period and the last shown in table 1, the cholera death rate fell by 73%. Thus, its decline was one of the significant drivers of Bengal's mortality transition. Secondly, due to its nature as a waterborne disease, and the fact that it is caused by fecal contamination of water supplies and inadequate waste disposal, it was highly likely to react to improvements in water provision, filtration, and waste disposal systems. Lastly, many cholera death rates stemmed from famines and water shortages, and others were more to do with water quality. Bengal is an example of the latter.

Therefore, although cholera response was bound up with famine response in South or West India, in Bengal, water quality was more directly the target.

This paper will first quantify the extent to which progressive improvements in sanitation through capital investment in waterworks, drainage, and sewerage reduced cholera death rates. The cumulative capital investments made over the period will be a proxy for the level of sanitary development. I will examine data on cholera death rates for the entire province of Bengal, between rural and urban areas, and towns in which major works in sanitation were carried out. By doing so, we will better understand the mechanisms of specific sanitary projects and their localized influence. I will then compare changes in cholera deaths between towns where major sanitary schemes took place and towns which did not receive major investment. My research will generate a comprehensive cross-spatial and cross-temporal report of Bengal's sanitary development, to evaluate the influence of public health factors on disease containment and their effectiveness in reducing deaths. The wider objective of this paper is to provide a historical account for the medical connection between sanitation and mortality, and to supplement further debate on the effects of colonial intervention in South Asia.

1.6 Presentation of primary sources

To achieve this, I will build upon an original dataset constructed from 3 different primary sources. The first is the Annual Report of the Sanitary Commissioner for Bengal, a colonial government report of public health statistics which was published every year between 1868 and 1919. It contains vital statistics on birth rates, death rates, chief diseases, disease prevention schemes, urban and rural sanitation, and civil sanitary initiatives. However, the data recorded in these reports substantially change after 1905 following the first major partition of Bengal. I have therefore chosen 1906 as the start of my observations for data on provincial deaths rates and public health expenditure. I have compiled data on cholera death rates and population data for every major town in Bengal. I have also drawn data on meteorological factors which may have influenced disease conditions and death rates, like rainfall and natural disasters, which I will include in my estimation model. Moreover, I have collected data on localized major works on water provision, drainage, and sewerage from 1913 and onwards. This is because of the reorganization of Bengal in 1912, which moved certain districts of some divisions into other provinces, and made the divisions of Bihar and Orissa, which had hitherto been part of Bengal, into its own province. I have not included data on these divisions in my estimates, and the major works I have covered are those that remained part of Bengal after its reorganization, which constitutes almost all of them.

The province's reorganization conveniently coincides with the first Annual Report of the Sanitary Engineer of Bengal, which was released from the years 1913 to 1931. This report is beneficial as it contains vital data for my research regarding all the water-supply schemes, and drainage and sewerage schemes in Bengal's districts and towns. A problem faced in assessing major sanitary works using this report is that it abruptly ends in 1931 and is not included as part of the new public health reports. Whilst this is not ideal as it limits my assessment of the impact of localized projects, it remains an adequate timeframe to examine their effect on death rates. The entire report is contained within the Annual Report of the Sanitary Commissioner for Bengal, and the Bengal Public Health Report, which is the final source I have drawn from.

The Bengal Public Health Report is a continuation of the first source but as part of a larger, and more extensive report. It is a governmental report published by the Department of Public Health and includes additional data on vaccinations (which belonged prior to a separate report), public health laboratories, school hygiene, and educational propaganda and publicity. For this report, I have collected the corresponding data regarding population, deaths, and meteorology for the subsequent years. The population data presented in these reports are taken from the decennial censuses of India. For the purposes of analyzing the effects on population on death rates for each year, I have assumed linearity between the census years for population growth.

As primary sources, these reports present a host of benefits. The data on death rates and sanitary investments are given by province, by division, by district, and by the towns and rural areas withing these districts, allowing me to assess sanitary investments and cholera deaths at the macro and micro-level. The data I have compiled on sanitary works by towns offers a much larger sum of observations which guarantee a certain level of statistical power. Furthermore, by examining the data at this level of observation, I can employ statistical methods that are tailored to panel datasets, such as fixed effects, to tackle endogeneity concerns and generate more accurate estimations of causal effects.

2. Dealing with Cholera

The 19th and early 20th centuries in India were marked by a notable characteristic - the government's failure to effectively address the issue of cholera. The lack of proactive measures to prevent the spread of the disease was influenced by political, economic, and medical constraints, which generated a palpable sense of apprehension among policymakers. However, with the intensification of epidemics due to the evidently poor sanitary conditions, the government were eventually forced to address these obstacles and act. Subsequently, the government-initiated reforms in public health strategies, placing greater emphasis on sanitary development. As a result, there was a significant increase in the allocation of capital towards the implementation of waterworks, drainage, and sewerage schemes, aimed at mitigating the prevalence of cholera. In this section, I will first explore how colonial authorities dealt with obstacles in dealing with cholera, through foundational measures taken in the late 19th century, and the more substantial changes in the 20th century. Secondly, I will graphically analyze the progression of investments into sanitary works between urban and rural areas, and major projects in waterworks and drainage undertaken in cities and towns. Lastly, I will further my analysis of these categories by demonstrating the trends of these investments in relation to cholera deaths rates for each of them.

2.1 Obstacles in dealing with cholera

2.1.1 Indigenous culture and religion

The colonial administration in India faced several practical challenges in dealing with cholera, particularly the indigenous hostility towards state intervention. There was a pervasive fear amongst policymakers that the dogmatic beliefs of the indigenous could exacerbate panic and unrest, especially during epidemics, leading to conflicts and political disorder. Epidemics in the 19th century were often associated by natives with the "trauma of conquest" and foreign rule.[19] The dissemination of Western medical techniques was not straightforward, as it conflicted with traditional Indian folk medicine and cultural superstitions, and inoculations were met with scepticism.[20] Measures regarding water sanitation were rejected due to beliefs that natural rivers had healing properties. The Ganges River in Calcutta being a primary example of the ritualization of bathing and washing in water sources which were for a long time, unregulated and infested with bacteria and harmful microbes.[21] Although some imported techniques, such as homeopathy, were accepted on the grounds of being closer to the traditions of Indian medicine, religious practices, pilgrimages, and festivals continued to occur without proper sanitary and medical regulation.[22] These congregations were a nexus for disease dissemination. The spread of cholera during festivals and pilgrimages made it difficult for the British to take control over the disease death toll. Prohibiting such practices would have been seen as an outrage on religious sentiments, and the colonial administration did not want to provoke religious and political backlash, given the risk of mutiny and rebellion. The measures that were taken by the government to control cholera, limited as they were, often generated precisely the kind of backlash that they had feared and long used to justify their laissez-faire approach to dealing with cholera. Many shared the belief that it would be better for the region to be "devastated by cholera than subjected to religious persecution", and such

[19] Arnold, *Cholera and Colonialism in British India*, 128.
[20] Ibid. 136-8.
[21] Pradip Kumar Bose. *Health and Society in Bengal: A Selection from Late 19th-Century Bengali Periodicals.* (New Delhi: SAGE Publishing India, 2006), 38.
[22] Ibid. 21, 38.

endorsements justified the prolonged inaction which allowed cholera to flourish.[23]

2.1.2 Financial constraints and medical uncertainties

Disputes over the expected returns from sanitation schemes had held back major investment in waterworks, sewerage, and drainage infrastructure for a long time. Arnold claims that the colonial regime was simply not prepared to commit substantial parts of its income to a focused cholera-eradication program, as methods of raising funds to sustain these projects, for example, through taxation of cultural and religious pilgrimages, were met with administrative as well as religious objections.[24] Other methods for raising funds were met with common negligence towards sanitation amongst taxpayers. This is evidenced in the sanitary report of 1916 by the discontinuance of the Patna system of village sanitation in Midnapore, where villagers generally rejected the importance of sanitary measures.[25] Complaints amongst the indigenous were almost universal, and there seemed to be little prospect of improvement until people realized the value of sanitation and were prepared to allocate resources to improving it. The British government did make some efforts to mitigate diseases, but they faced limitations due to shortages in medical officers and insufficient funds. As a result, their primary objective was to alleviate suffering and provide remedial services. The responsibility of research into medical and sanitary techniques, and public health provisions were considered the sole responsibility of the state, with no assistance from private or volunteer organizations. However, the government had long overlooked the importance of prevention and environmental hygiene. It wasn't until the late 1800s that they recognized the potential to mitigate disease death tolls.[26] But subsequent efforts to strengthen public health services were going to take time to get right.

[23] Arnold, *Cholera and Colonialism in British India*, 143.
[24] Arnold, *Cholera and Colonialism in British India*, 143
[25] Sanitary Commission, Bengal (India), *Annual Report of the Sanitary Commissioner for Bengal, 1916,* (Calcutta: Bengal Secretariat Press, 1917), 24.
[26] Mushtaq, *Public Health in British India,* 9

The indecisiveness of the colonial administration in dealing with cholera was exacerbated by uncertainty over its nature and mode of transmission. Until the 1880s, the government believed that cholera was not contagious and attributed it to environmental causes such as atmospheric vicissitudes, poisonous emissions, effluvia, miasmas, overcrowding, and rotting vegetation.[27] Despite recognizing the dangers of epidemic cholera, the colonial regime was slow to respond to the threat it posed to Indian subjects.

Financial constraints, political expediency, and fears of resistance persisted throughout the 1800s, hindering interventionist policies. By the end of the 19th century, with the increased pressures of disease devastating both British settlers and the indigenous population, along with breakthroughs in medical research, plans were made, and bills were passed to transform sanitary conditions and provide comprehensive public health services.

2.2 Laying the foundations: sanitation policy in the 19th century

Whilst focused initiatives to improve sanitary conditions were largely absent in Bengal during the 19th century, significant steps were taken by colonial authorities which lay the foundations for the advancements made in the 20th century. Interventionist policies started off with the intention to contain disease only for the relief of British soldiers. Troops were particularly susceptible to diseases that flourished in the insanitary and crowded conditions of barracks and encampments, and when infected, became principal agencies by which cholera disseminated through India.[28] In 1863, commission reports inquired into disease mortality amongst British troops in India and found that 69 out of every 1000 troops died from tropical diseases including cholera. The Military Cantonment Act of 1864 was passed to improve military hygiene. And the central commission recommended the establishment of a department of public health in each province to undertake projects on sanitary development and disease prevention schemes in civil society for improving the health of the

[27] Arnold, *Cholera and Colonialism in British India*, 144.
[28] Ibid. 126.

British Army.[29] The 1868 international sanitary conference in Constantinople urged governments to take more action in dealing with cholera.[30] In response, sanitary boards were set up to improve the civil sanitary conditions and provide vaccinations. By 1879, all provinces had their own local sanitary departments, and in 1880, each province was assigned a chief sanitary engineer.[31] The period saw a massive increase in sanitary inspections, vaccination provisions, and data collection, which would be compiled in a report annually (from which I will empirically assess the effects of sanitary works later in this paper), and used as means to inform future policies and incentivize further investment into projects. The intensification of outbreaks at religious pilgrimages, and cultural fairs forced government to take bolder steps despite the feared and inevitable backlash. Alleged fatalism and hostility amongst indigenous people were no longer seen as an adequate reason for state abstention.[32] The period also saw a dramatically widening gulf between European and South Asian medicine. The rapid advances in Western medical science put great emphasis on sanitation and hygiene due to breakthroughs like germ theory and 'contagionism'.[33] It was only until 1890 when doctors had reached consensus on the nature of cholera as a waterborne contagion, which set precedent for a flurry of investment into clean water provision and adequate waste disposal systems. But investment remained slow in the 19th and early 20th century. Efforts were made to increase funding towards sanitary works through self-government policies to improve sanitation at the local level, but local bodies failed to sustain planned investments due to lack of staff.[34] Only by 1912 was this problem addressed by the central government, as local bodies were paired with government health officers and provided with funding.[35]

[29] Mushtaq, *Public Health in British India*, 8
[30] Ibid. 10
[31] Chittabrata Palit and Tinni Goswami. "Sanitation, Empire, Environment: Bengal (1880-1920)." Proceedings of the Indian History Congress 68 (2007): 731–44. http://www.jstor.org/stable/44147883. 732-3; See also: Mushtaq, *Public Health in British India*, 8
[32] Arnold, *Cholera and Colonialism in British India*, 149
[33] Ibid. 135-6
[34] Palit and Goswami, *Sanitation, Empire, Environment: Bengal (1880-1920),* 732
[35] Mushtaq, *Public Health in British India*, 8

2.3 Sanitary works in the 20th century

It was only until the 1920s and 30s when colonial authorities began to really capitalize on the advances of the late 19th and early 20th centuries. According to Figure 1, there was a noticeable increase in annual public health expenditure in Bengal from the mid-1920s and onwards. By the 1930s, real public health expenditure was substantially higher than the preceding years, demonstrating the increase in focus towards public health initiatives.

The period was also largely absent of famines. It is important to note that a reason which assisted the decline in cholera deaths in Bengal was reduced famine occurrence between the 1920s and early 40s, and the resurgence of famine in 1943 seems to support this. Historians have sometimes made the mistake of assuming that cholera deaths are simply an indicator of famine mortality, but this is not necessarily the case. Although concurrent famines greatly inflated the human toll of cholera epidemics, there was no automatic correlation between the two. Epidemics followed their own seasonal and cyclical patterns.[36] Despite slow progress in sanitation and public health schemes, major cities showed a decline in mortality rates, which eventually spread to smaller towns. Therefore, while famine and cholera often occurred together, it is important to understand that each had its own distinct impact and patterns of occurrence.[37]

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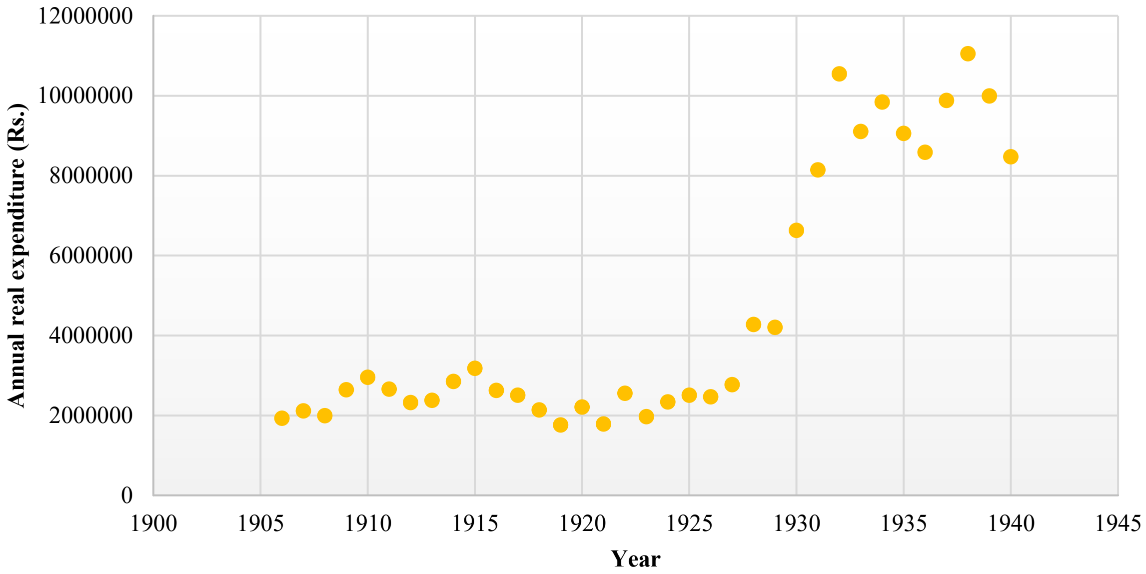
[36] Arnold, *Cholera and Colonialism in British India*, 125

[37] Arup Maharatna. "The Demography of Indian Famines: A historical perspective." *PhD Thesis, London School of Economics and Political Sciences* (1992). http://etheses.lse.ac.uk/id/eprint/1279. 108

Figure 1. Total Annual Expenditure on Public Health in Bengal between 1900 and 1941(in real terms)



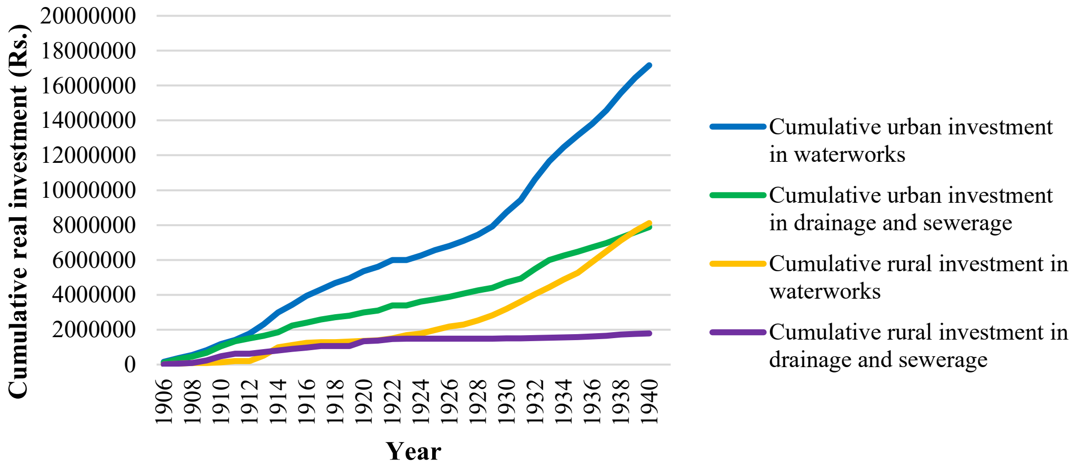
Note: Total Expenditure on Public Health in Bengal was calculated by summing up urban, rural, and village expenditures. I have deflated all nominal values to show real figures by obtaining yearly price indices from Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health Report 1929-41.*

Colonial expenditure in the 20th century was distributed to many different aspects of public health, including the construction and improvement of water supplies, drainage and sewerage systems, general conservancy, disposal of dead bodies, the construction of marketplaces and slaughterhouses compliant with sanitary standards, treating the sick, vaccination provision, and other miscellaneous sanitary works.[38]

There was a substantial difference in expenditure between urban and rural areas, and between the two biggest streams: waterworks, and drainage and sewerage. Figure 2 shows that the most significant investments made between 1906 and 1941 were investments in waterworks in urban areas. For urban areas, investment in waterworks greatly exceeded investment in drainage and sewerage, as well as both streams for rural areas.

[38] Sanitary Commission, Bengal (India), *Annual Report of the Sanitary Commissioner for Bengal, 1906*, (Calcutta: Bengal Secretariat Press, 1907), Section IX, 22

Figure 2. Cumulative real investment in sanitary works between urban and rural areas for period 1906-1941

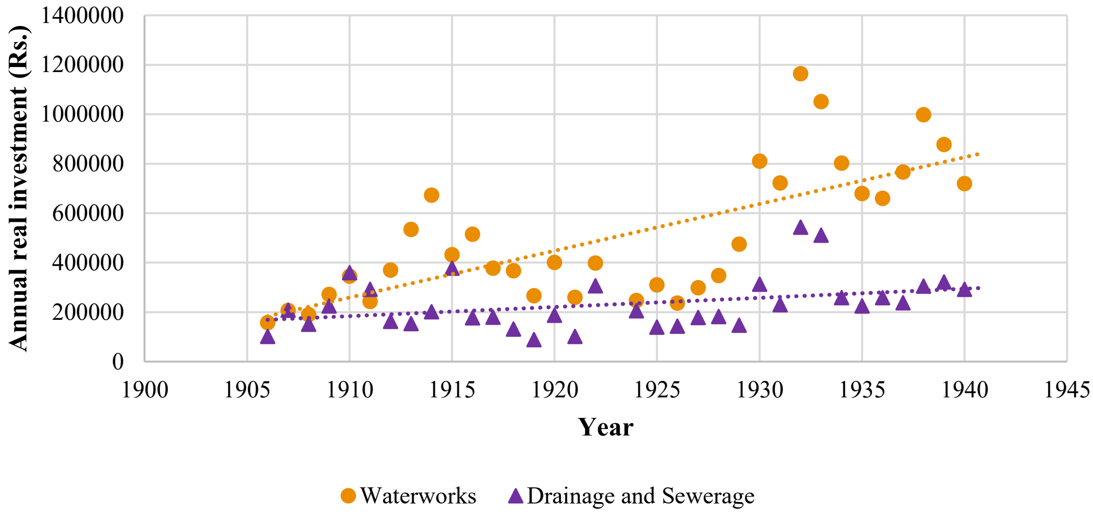


Note: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health*

2.3.1 Trends in urban expenditure in relation to urban cholera deaths

According to figure 3, annual real investment in waterworks for urban areas had peaks in the 1930s, but the general trend does not closely follow any linear or exponential path. However, between 1906 and 1941, there is a general upward trend in annual investments in waterworks. Annual investment in drainage and sewerage in urban areas does not show any consistent pattern of increase. The effects of money being put into waterworks, and into to drainage and sewerage, and their relative significance on cholera deaths rates remains to be seen. For now, the movement of investments suggests waterworks may have had a greater impact on cholera deaths than drainage and sewerage.

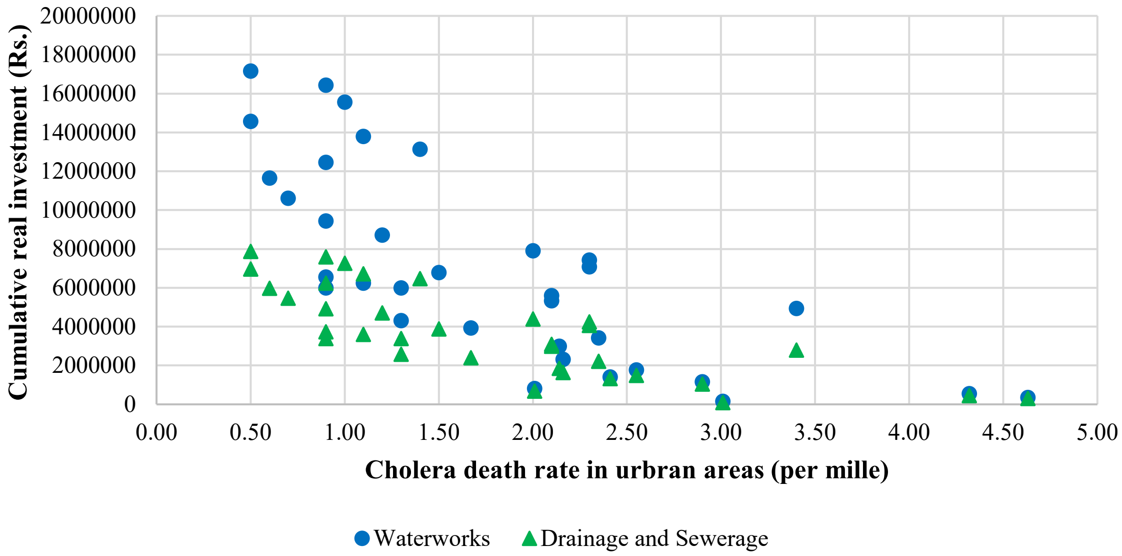
Figure 3. Annual real investment on waterworks, and drainage and sewerage systems in urban areas between 1906 to 1941



Note: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health*

If we make our data on both types of sanitary investments cumulative, we see stronger correlative relationships between both streams and cholera death rates. This is shown graphically in figure 4 and confirmed in table 2, as the correlation coefficients are close to -1. This implies that the variable which is more likely to be explanatory is the cumulative investment in sanitary works and not the marginal investments made incrementally each year. This makes sense as cumulative investment represents the extent to which projects were developed and improved up until the year in question. In other words, the cumulative investment in any given year should act as a proxy for the degree of sanitary development in that year.

Figure 4. Correlation between cumulative sanitary investment and cholera death rates in urban areas for each year between 1906 and 1941



Note: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health*

Table 2. Correlation matrix for urban sanitary investment and cholera deaths

	Cholera death rate per mille
Cholera death rate per mille (in urban areas)	1
Urban Investment on Waterworks (Cumulative)	-0.7475503
Urban Investment on Drainage (Cumulative)	-0.7749871
Urban Investment on Waterworks (Annual)	-0.6840926
Urban Investment on Drainage (Annual)	-0.4263454

Note: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health Report 1929-41.*

2.3.2 Trends in rural expenditure in relation to rural cholera deaths

Rural and village areas did not benefit from advancements in sanitation as much as towns and cities, and the amount of investment allocated to these regions reflects this (figure 2). It was arguably more sensible to start major sanitary works in urban areas, as people who lived in major cities and towns were more susceptible to diseases, especially cholera, as fecal contamination of water sources was more likely in crowded conditions. Generally, waterborne disease proliferation was inversely proportional to regional population density. It was therefore not as much of a pressing concern to adopt the same level of sanitary reform in rural areas as it was in urban towns. Also, major developments were less feasible to carry out in rural areas for 2 reasons. Firstly, tax revenues were smaller in rural areas than in cities and towns, and so fewer funds were available to redistribute in the form of public health services. Secondly, most people living in the countryside were living in remote areas and farms which were distanced apart. It was therefore a difficult task to develop waterwork, drainage, and sewerage systems that could serve large numbers of rural inhabitants contemporaneously. Because of these reasons, it was likely that the few investments that were made into sanitary work in rural areas had less of an effect on cholera mortalities than the major investments made in towns. Table 3 supports this, showing a relatively weaker correlation between rural investments and cholera death rates.

Table 3. Correlation Matrix for rural sanitary investment and cholera deaths

	Cholera death rate in rural areas per mille
Cholera death rate in rural areas per mille	1
Rural Investment on Waterworks (Cumulative)	-0.552533968
Rural Investment on Drainage (Cumulative)	-0.510202572
Rural Investment on Waterworks (Annual)	-0.508702263
Rural Investment on Drainage (Annual)	0.011085655

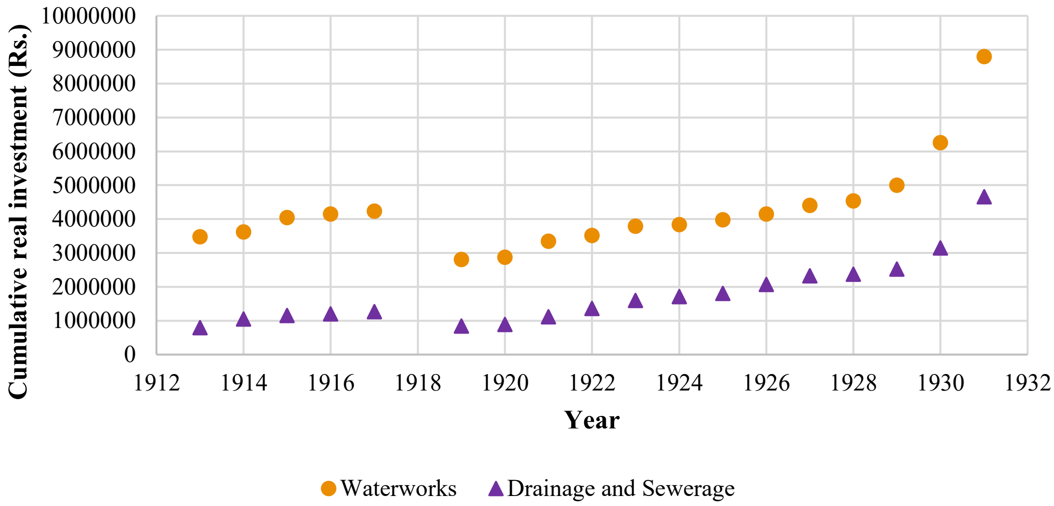
Note: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2.
Source*: See Table 2*

2.4 Waterworks, drainage and sewerage in cities and towns

Major works in these three streams of sanitary development have been detailed extensively in the Annual Reports of the Sanitary Engineer in Bengal, from 1913 to 1931. Up until the last report in 1931, colonial authorities had commissioned investment toward 45 waterwork projects, and 33 drainage and sewerage schemes, in different towns and cities spread across 20 districts in all of Bengal's provinces: The Presidency, Burdwan, Rajshahi, Dacca, and Chittagong. 41 out of 45 waterwork projects were completed by 1931. Majority of the completed projects were opened for public use between 1913 to 1931, serving a population of approximately 1,126,099 during the year 1931. Average daily supply of water for the year in all towns aggregated to 15,092,459 gallons. Of the 33 drainage and sewerage works reported in 1931, 3 were still in development, and the rest were serving an approximate population of 602,034 during the year. Total investment up until 1931 on waterworks and drainage projects was 15,347, 273 Rupees and 615,483 Rupees respectively.[39] Marginal increases in real investment were most prominent in the late 1920s and early 30s, as shown in figure 5.

[39] Bengal public health report 1931, 136-148

Figure 5. Cumulative real investment on major waterworks, drainage and sewerage projects in cities and towns from 1913 to 1931

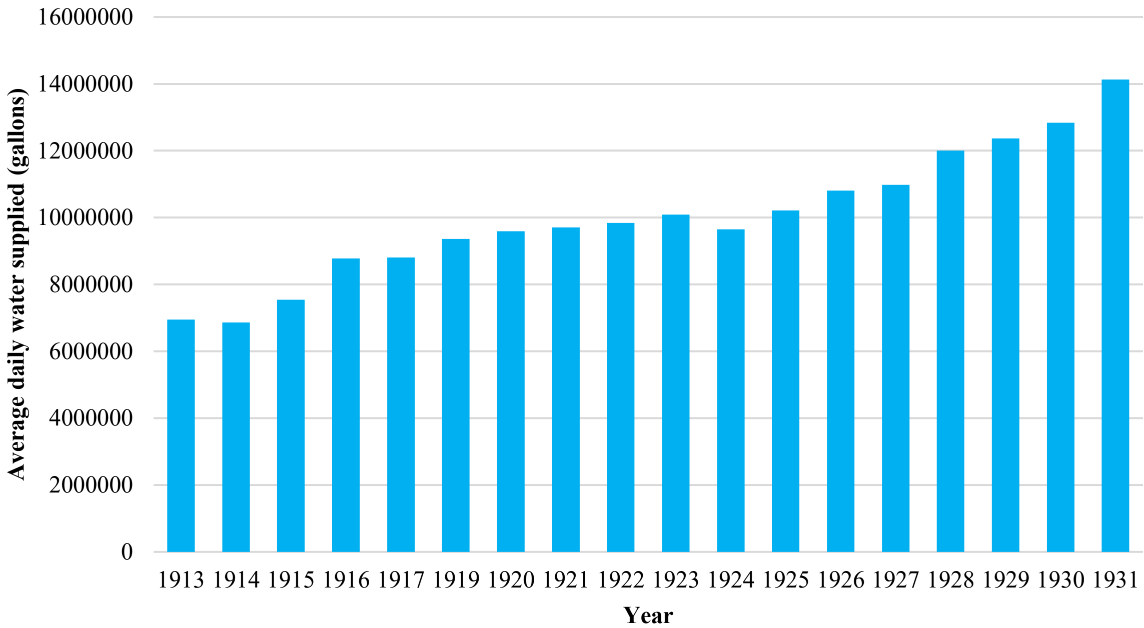


***Note**: All nominal investment values have been deflated to show real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2*

***Source**: Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health*

Water supply systems were of many different varieties depending on the region. Towns and cities which were situated near, or around large rivers mainly used them as the main supply of water. Some towns had other natural sources like springs. For towns that didn't have a natural water source, tube wells, and bore holes were developed, and some were connected with water systems built in local mills, or other towns. Each water supply system was fitted with an engine or specialized pump to propel water from the source, into the filters for cleansing, and finally to access points for people to use. Different water filters were used, such as slow sand filter beds, pressure filters, gravity filters, and mechanical filters. Sand filters were applied mostly in systems that drew water from rivers, to parse out sand and other particulates that are commonly found in river waters. During the 20th century, engineers introduced numerous advancements and innovations in the field of water sanitation, including pressure, gravity, and mechanical filters. These cutting-edge filters proved to be significantly more efficient in separating particulates and eliminating contaminants from water, resulting in enhanced purity levels. As a result, filters became increasingly popular and were widely adopted in water supply systems to improve the quality of drinking water. In addition, figure 6 shows that waterwork developments were increasing the average daily amount of water supplied. Also, by 1931, water supplies were serving 47% more people than they were in 1913.[40] Given these observations, it seems that progressive increases in capital investments were improving both the quality and quantity of water supplied, enabling the use of this variable as a proxy for sanitary development in terms of clean water provision.

Figure 6. Average daily supply of water by major waterworks in cities and towns from 1913 to 1931



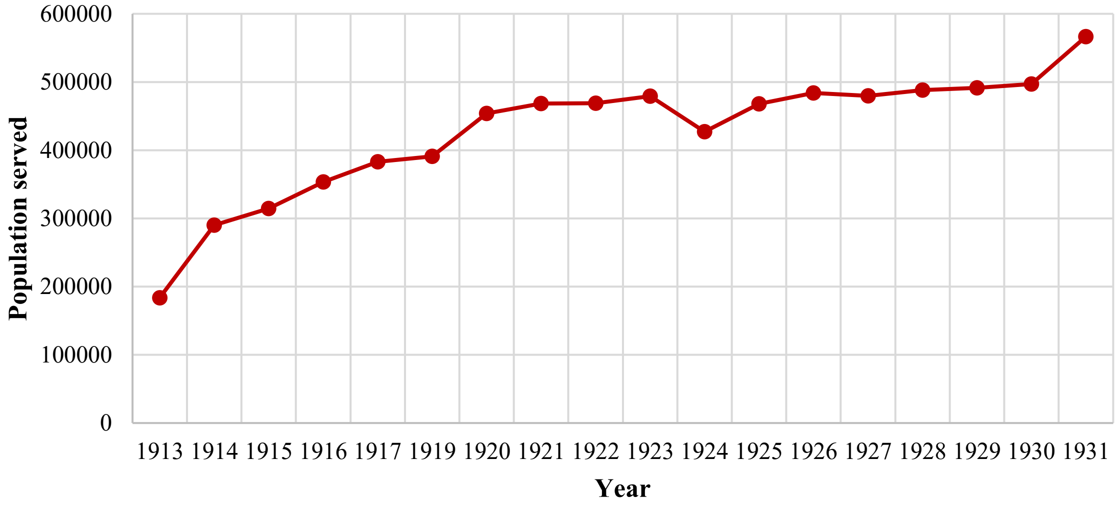
***Source**: Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health Report 1929-41, Annual Report of the Sanitary Engineer for Bengal 1913-31.*

Drainage and Sewerage projects were less advanced in this period. Developing these systems to a high standard was a much greater task than developing clean water supplies. Construction of a comprehensive drainage and sewerage infrastructure for each town would require more investment than what was available, and the existing standards of waste disposal were little to non-existent. Therefore, most of the systems were developed in towns which needed

[40] Sanitary Commission, Bengal (India), *Annual Report of the Sanitary Engineer, Bengal*, 1913, (Calcutta: Bengal Secretariat Press, 1915), Appendix, Statement No.1, 37; Department of Public Health, Bengal (India), *Annual Report of the Chief Engineer, Public Health Department, Bengal*, 1931, (Calcutta: The Bengal Secretariat Book Depot, 1933), Appendix, 136.

them the most. Towns which had frequent sewage overflows due to unstable sewerage connection within privies were priorities for investment.[41] Waste disposal systems were relatively primitive and underdeveloped compared to Western standards (where individual homes were connected to a centralized sewer system). Whilst advancements in drainage and sewerage in Bengal were slight, figure 7 shows that for the most part, the number of inhabitants who were served by drainage and sewerage developments increased between years, and for the whole period, increased substantially, by over 200%. Similar to the prior observations on waterworks, it is clear progressive capital investment into drainage and sewerage were improving sanitary conditions, albeit to a lesser extent. Therefore, the observations so far imply that the effect of improvements in drainage and sewerage may have had less of an effect on cholera mortality than improvements in waterworks. I will test this in the next section.

Figure 7. Population served by drainage and sewerage in cities and towns from 1913 to 1931



Source*: Annual Report of the Sanitary Commissioner for Bengal 1906-1928, Bengal Public Health Report 1929-41, Annual Report of the Sanitary Engineer for Bengal 1913-31.*

[41] Department of Public Health, Bengal (India), *Bengal Public Health Report, 1929*, (Calcutta: The Bengal Secretariat Book Depot, 1931), 131.

3. Econometric analysis

3.1 Effect of waterworks, drainage, and sewerage using a fixed effect model

In this section, I will attempt to confirm the predictions stemming from the secondary literature and graphical analysis that gradual increases to sanitary provisions through major investments in waterworks, drainage, and sewerage reduced cholera death rates in urban Bengal. I will separate the effects of waterwork developments, from drainage and sewerage developments by treating them as distinct dependent variables. I will run a fixed effects regression using a panel dataset, using data on the levels of cumulative real investment allocated to major projects in towns across Bengal's five divisions between 1913 and 1931. Within these divisions, major works were carried out in 49 towns, spread over 20 districts. Therefore, my panel dataset includes 49 observations spanning over 18 years. The nature of my dataset allows me to incorporate town fixed effects controlling for permanent town specific characteristics that would be correlated with cholera death rates and investment provision in major sanitary works. I will not be including time fixed effects, as I am assessing the impact of major sanitary investments over time, so removing over time variation by including time fixed effects will prevent my model from predicting the effect of changes to investments over time on cholera death rates. Therefore, the baseline regression model is:

$$Y_{it} = \alpha + \beta_1 W_{it} + \beta_2 DS_{it} + \delta_i + \varepsilon_{it} \qquad (1)$$

where Y_{it} is the cholera death rate per mille in town i in year t; W_{it} is the real investment in major waterworks projects in town i up until year t; correspondingly, DS_{it} is the real investment in major drainage and sewerage projects in town i up until year t; δ_i is the town fixed effect; and ε_{it} is the error term.

For the model to accurately measure the causal impact of major sanitary investments on cholera death rates, it is crucial that the error term is not correlated with the primary regressors, W_{it} and DS_{it}. To mitigate omitted variable bias, I will select two variables which represent environmental pressures which might have influenced cholera occurrence. Control of local water supplies was made difficult due to inconsistent rainfall. Excessive rain would overwhelm Bengal's underdeveloped irrigation and canal systems, creating stagnant pools of water which became vectors of waterborne diseases like cholera. On the flip side, deficient rainfall put pressure of agricultural yields increasing scarcity and food prices, which ultimately resulted in shortages, and at worst famines.[42] Food shortages because of deficient rainfall made resistance to diseases less likely and would have increased the occurrence of cholera and other diseases. Also, regional disturbances from natural exogenous shocks, such as typhoons, cyclones, and floods affected pre-existing poor water and sewerage systems, inflating cholera mortalities as well.[43] To control for disparities in rainfall and exogenous shocks between towns, I will include a dummy variable for each in my regression model. I have extracted data on rainfall and natural disasters from the meteorology section of Bengal's public health report for each year.

Another potential source of omitted variable bias concerns comes from the correlation between fecal contamination of water sources and population density. The higher the population density, the higher the likelihood of fecal contamination and the subsequent transmission of waterborne diseases. Towns which were more densely populated were more likely to have higher cholera death rates as a result. I will therefore use population per town as a proxy for population density, given that most towns were homogenous in terms of area covered.

[42] Roy, *End of Famine*, 111-2, 119-20

[43] Tony Fredrick et al. "Cholera Outbreak Linked with Lack of Safe Water Supply Following a Tropical Cyclone in Pondicherry, India, 2012." J Health Popul Nutr. 33, no. 1 (2015): 31-38. https://pubmed.ncbi.nlm.nih.gov/25995719/. 31-2

Table 4. Effect of major investments in waterworks, drainage, and sewerage on cholera deaths rates in towns across Bengal from 1913 to 1931

Variable	Y_{it}				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Waterworks	-0.0669**	-0.0685**	-0.0787***	-0.0726**	-0.0753*
	(0.0222)	(0.0226)	(0.0230)	(0.0232)	(0.0360)
Drainage and Sewerage		-0.0391	-0.0462*	-0.0403	-0.0688
		(0.0232)	(0.0227)	(0.0228)	(0.0420)
Population			0.00000761**	0.00000701**	-0.0000483**
			(0.00000238)	(0.00000245)	(0.0000158)
Rainfall dummy	No	No	No	Yes	Yes
Natural shocks dummy	No	No	No	Yes	Yes
Town fixed effects	No	No	No	No	Yes
R^2	0.021	0.027	0.023	0.030	0.047
N	837	837	837	837	837

Note: dependent variable is cholera death rates per 1000 (or per mille) citizens in town i in year t as defined in the text. I have taken the log values of cumulative real investments to adjust the coefficients to the scale of cholera death rates per mille. Robust standard errors are in parentheses. ***Significant at the 0.1% level. ** Significant at the 1% level. *Significant at the 5% level.
Source: data on mortalities and population come from the appendices of Section V of the Annual Report of the Sanitary Commissioner for Bengal 1906-1928 and Chapter II of the Bengal Public Health Report 1929-41. Data on rainfall and natural disasters come Section I: Meteorology in the Annual Report of the Sanitary Commissioner for Bengal 1913-1928, and Chapter I of the Bengal Public Health Report 1929-31. Data on investments in major sanitary works come from the Annual Report of the Sanitary Engineer for Bengal 1913-31. All nominal investment values have been deflated to real figures using Michelle McAlpin's "Price movements and Economic fluctuations" in the Cambridge Economic History of India, volume 2

The regression specification I will therefore use for the remainder of this section is:

$$Y_{it} = \alpha + \beta_1 W_{it} + \beta_2 DS_{it} + \gamma_1 Pop_{it} + \partial_1 Rd_{it} + \partial_2 NSd_{it} + \delta_i + \varepsilon_{it} \qquad (2)$$

where Pop_{it} is the number of citizens in town *i* in year *t*; Rd_{it} is the dummy variable for rainfall in town *i* in year *t; NSd_{it}* is the dummy variable for natural shocks in town *i* in year *t*; and all other variables are the same as above. Table 4 presents the results of this regression where Y_{it} is the cholera death rate per mille between 1913 and 1931.

The standard OLS regression in columns (1) to (3) confirm the observations previously made. As the level of real investment in major waterworks in town i up until year t increases, the cholera death rate decreases. For waterworks, the results are statistically significant. However, the corresponding effect of real investment in drainage and sewerage projects in town i up until year t are only significant when including the Pop_{it} in the regression. More specifically, in column (3), the coefficient of W_{it} indicates that a 10-percentage point increase in the level of real investment in major waterworks decreased cholera deaths by 0.003 per mille, and the coefficient of DS_{it} indicates that for the same increase in real investment, cholera deaths decrease by 0.001 per mille.[44] As predicted in the last section, the effect of investments in waterworks is greater than the effect of investments in drainage and sewerage on cholera death rate in towns. The coefficients are very precisely estimated and are significant at the 0.1% and 5% significance level, respectively. As demonstrated in column (4), the effect of waterwork investment is robust to the inclusion of our dummies for environmental influences ($Rd_{it} + NSd_{it}$) on cholera deaths. In this case, the coefficient decreases slightly to -0.0726, which corresponds to what the omitted variable bias formula predicts after the inclusion of variables which are (like the dependent variable W_{it}) negatively correlated with cholera death rates. However, the same cannot be said for the effect on investments in drainage and sewerage, as the inclusion of environmental factors in column (4)'s regression produces a coefficient for variable DS_{it} which is not significant.

Column (5) represents the preferred specification, as it includes a full set of controls ($Pop_{it} + Rd_{it} + NSd_{it}$) and town fixed effects (δ_i). The inclusion of town fixed effects allows for the control of important permanent town-specific characteristics that may be correlated with cholera death rates and levels of investment in major sanitary developments. Current historians have evidenced wide disparities in disease mortality between regions in Bengal. Jameson noted

[44] As the independent variable was log-transformed, I multiplied the coefficient by log(1.1), which tells us the extent to which a 10% increase in the independent variable decreases the dependent variable.

that during early 19th century epidemics, towns higher up in the Ganges had suffered considerably less cholera deaths than those in Southern Bengal.[45] Different towns had vastly different experiences with cholera based on their location. Towns which were nearer to richer sources of water, like the main body of the Ganges River were less likely to face problems of fecal contamination. In contrast, towns which were situated between lakes, irrigation systems, and smaller offshoots of the Ganges were more susceptible to cholera, as contamination of these smaller and slower moving bodies of water were more likely. As smaller rivers and canals were geographically widespread, it made comprehensive sanitation more difficult. Also, cholera dissemination was more likely in towns which experienced greater flows of pilgrims. This was a problem for those towns which were majority Hindu, as many of their yearly rituals involved collective bathing in (and consumption of) natural waters, which were readily contaminated with fecal waste.[46] Moreover, towns closer to the main city of Calcutta, like English Bazaar and Cossipore-Chitpur benefitted from the city's highly advanced standards of sanitation. By the 1900s, Calcutta were miles ahead of any other town in the Bengal in terms of clean water provision, drainage, and sewerage, and often subsidized the sanitation of smaller towns on its periphery.[47] We can see in column (5) that the coefficient of waterwork provisions increases to -0.0753 after the inclusion of town fixed effects and is significant at the 5% significance level. In 1931, total investment made in waterworks was 153% higher than the 1913 amount. According to our coefficient, this increase in investment would yield a decrease in average cholera deaths per mille in towns by 0.07, accounting for a quarter of the decrease in average cholera deaths per mille of all towns served between 1913 and 1931.[48] In the prior section, I predicted that the effect of drainage and sewerage on cholera death rates would be less than waterworks given my observations on the level of

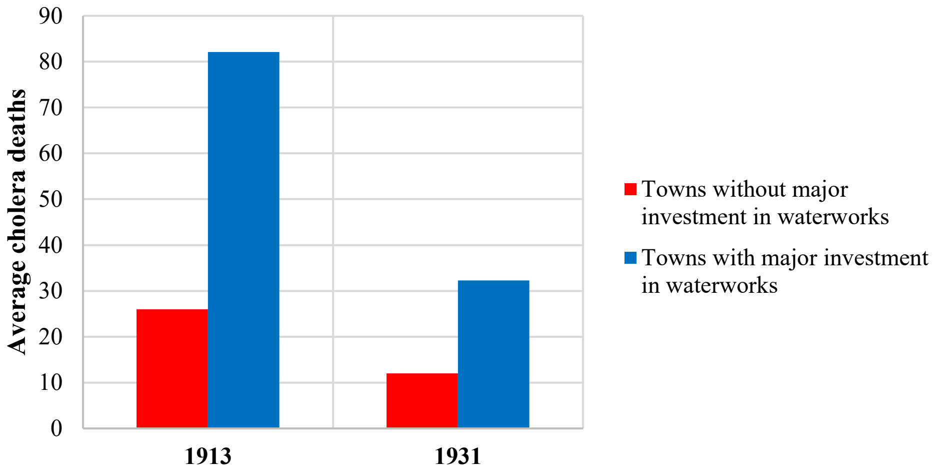
[45] Arnold, *Cholera and Colonialism in British India*, 121
[46] Arnold, *Cholera and Colonialism in British India*, 139
[47] Sanitary Commission, Bengal (India), *Annual Report of the Sanitary Commissioner for Bengal, 1913*, (Calcutta: Bengal Secretariat Press, 1914), 37.
[48] *Note:* As the independent variable was log-transformed, I multiplied the coefficient by log(2.53), which tell us the extent to which a 153% increase in the independent variable decreases the dependent variable.

investment provided and the nature of the systems which were built. The results in fact show that despite the efforts of the sanitary commission to apply some measures to improve drainage and sewerage, these investments did not have any significant effect on cholera death rates in the towns treated between 1913 and 1931. The results uphold that the mitigation of cholera deaths through sanitation were more to do with water provision than waste disposal.

3.2 Effect of waterworks using a difference-in-differences model

One possible drawback of the fixed effects model is that my panel dataset only includes data on towns which were served with major investment in waterworks, drainage, and sewerage. This omits many towns from the model which did not receive major investment. Although every town had rudimentary sanitary measures, only in the towns included in the previous model did there occur a major sanitary project from 1913 to 1931. The annual reports of the sanitary engineer of Bengal refers to many projects which were proposed to the sanitary commission, which were either still pending approval or rejected. Also, the reports show that sanitary practices like removal of dead bodies, fecal waste, cleaning of markets, river ghats, and houses, and cholera inoculations were becoming a more and more common and widespread overtime. However, these practices did not constitute major investment and their effects would have been miniscule compared to major works. The omission of towns which did not receive major investment was appropriate for the previous model's purpose to isolate the impact of major developments in the towns in which investment occurred. Given that standard sanitary practices were becoming more common and improving overtime notwithstanding major investment, it is likely that towns who did not receive major investment also experienced a fall in cholera deaths, albeit to a lesser extent than the towns which did, and this is supported by figure 8. Therefore, in this section, I will try to determine whether the difference in the change in cholera deaths from 1913 to 1931 between the two groups can be attributed to major investments in waterworks.

Figure 8. Average cholera deaths in towns which received major investment in waterworks versus towns which did not, in 1913 and 1931



Source: Annual Report of the Sanitary Commissioner for Bengal 1906-1928; Bengal Public Health Report 1929-41.

To do this, I will be employing a difference-in-differences (diff-in-diff) model to estimate the effect investments in waterworks had on the change in cholera deaths in towns where investment occurred (treatment group) compared to the towns where it did not occur (control group). The model will allow me to observe outcomes for the two groups, both before and after the investment provision. I will not be extending this analysis to investments in drainage and sewerage as the previous section demonstrates no significant effect of these investments in the towns served. If the results are robust and show a negative diff-in-diff coefficient, the inclusion of a counterfactual in my analysis will strengthen the claim that there is a causal relationship between clean water provision and waterborne disease mortality.

To achieve this, I have added every other town in Bengal (where major investments did not occur) to my existing panel dataset. This increased my observations to 108 different towns in 26 districts across Bengal's 5 divisions. The diff-in-diff model requires two distinct time periods to measure both groups before and after the investment provision. Although investment provisions were progressively added throughout the years between 1913 and 1931, for simplicity, I have filtered the dataset to two years, 1913 and 1931, representing the beginning of the major provisions, and the last year in which they were recorded. This will not show the effect the provisions had for each year but rather the effect of the total provisions made up until the end of the period. The underlying assumption of this model is that the time-varying factors are group invariant.[49] This means the trends in cholera death rates for both the control group and the treated group (had it not been for investment) are assumed to be parallel. As aforementioned, there was likely to be variance between towns regarding cholera deaths due to differences in population density and environmental factors. However, table 4 shows a very small coefficient for Pop_{it}, indicating that population density did not have a noticeable effect on cholera deaths, thus accounting for a negligible variance. Therefore, I can safely attribute any difference in trends between the two groups following investment to the investment (or treatment) effect. I will still include population as a variable in the new estimation model as it was nevertheless a robust result in table 4. I will let any remaining concerns about the parallel trends' assumption, and the inclusion of additional unmeasured variables for further research. The diff-in-diff model goes as follows:

$$y_{it} = \alpha + \beta Treat_{it} + \gamma Post_{it} + \lambda(Treat_{it})(Post_{it}) + \theta Pop_{it} + \varepsilon_{it} \qquad (3)$$

where y_{it} is the change in cholera deaths in town i in year t; $Treat_{it}$ = 0 if town i is in the control group, = 1 if town i is in the invested (treated) group; $Post_{it}$ = 0 if time period is before investment (1913), = 1 if time period is after investment (1931); $(Treat_{it})(Post_{it})$ is the interaction term, and its coefficient λ will tell us the average treatment effect (ATE). The diff-in-diff estimate or ATE is the difference in the treatment group before and after investment subtract the difference in the control group before and after investment.

[49] Coady Wing, Kosali Simon, and Ricardo A. Bello-Gomez. "Designing Difference in Difference Studies: Best Practices for Public Health Policy Research." Annual Review of Public Health 29, no. 1 (2018): 453-69. https://doi.org/10.1146/annurev-publhealth-040617-013507. 455-7.

Table 5 presents the results of the diff-in-diff estimation with an OLS regression where y_{it} is change in cholera deaths in 1913 and 1931.

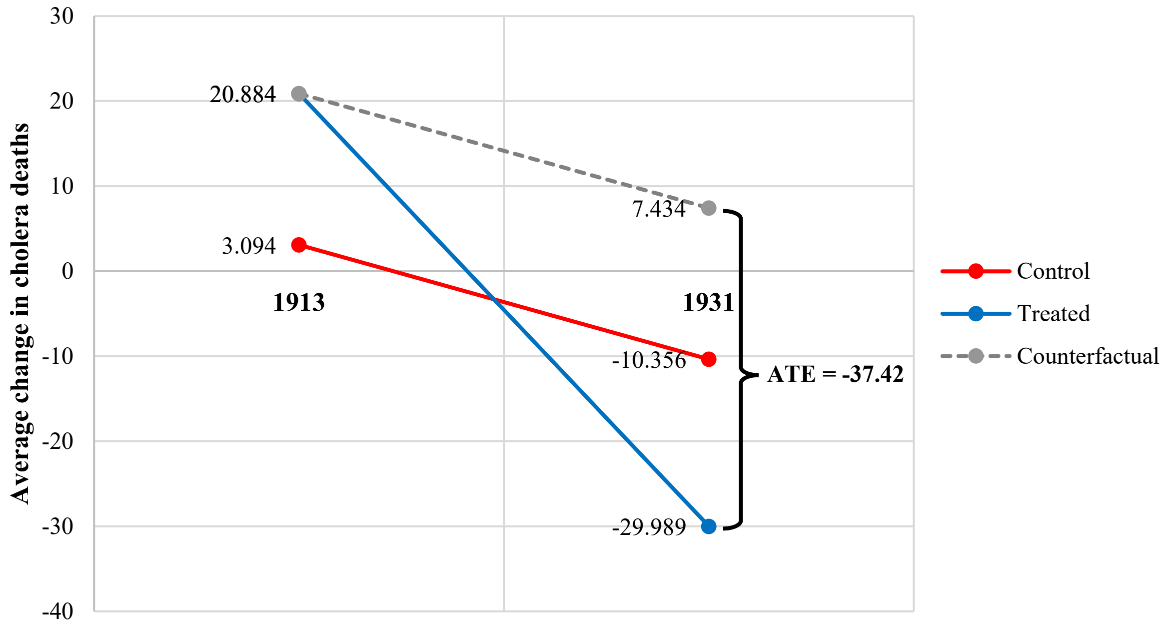
Table 5. Difference-in-differences estimation of the effect of major investments in waterworks on cholera deaths for towns in Bengal in the year 1913 and 1913

Variable	$\boldsymbol{y_{it} = \Delta choleradeaths}$
	Outcome
Constant (α)	3.094***
	(0.000)
Treatment (β)	17.79*
	(0.014)
Post-treatment (γ)	-13.45**
	(0.009)
Diff-in-Diff (λ)	-37.42***
	(0.000)
Population (θ)	0.0017***
	(0.000)

Note: dependent variable is change in cholera deaths in town i in year t as defined in the text. ***Significant at the 1% level. **Significant at the 5% level. *Significant at the 10% level.
Source: data on mortalities and population come from the appendices of Section V of the Annual Report of the Sanitary Commissioner for Bengal 1906-1928, and Chapter II of the Bengal Public Health Report 1929-41.

The results show coefficient α (constant) is significant and greater than zero, indicating towns which did not receive major investment (control group) experienced an average increase in cholera deaths by 3.094. The coefficient β is also significant and greater than zero, indicating that in 1913, average change in cholera deaths for the treatment group was different from the control group. Specifically, towns in the treatment group had an average change of 17.79 cholera deaths higher than towns in the control group. The average change in cholera deaths in towns which received major investment (treatment group) in 1913 is therefore, 3.094 + 17.79 = 20.884. Moreover, the coefficient γ is significant and less than zero, suggesting that average change in cholera deaths in towns in our control group decreased between 1913 and 1931 by 13.45. Therefore, the average change in cholera deaths for towns in our control group in 1931 is 3.094 – 13.45 = -10.356. Finally, the coefficient λ (ATE) is significant and less than zero, thus confirming a negative causal relationship between major investments in clean water provision and changes to cholera mortality. Particularly, average change in cholera deaths decreased by 37.42 more than it would have without the provision of major investment. This is shown graphically in figure 9. Had it not been for major waterwork developments in 'treated' towns, average change in cholera deaths would have been positive in 1931, albeit on a downward trend. The major investment accelerated this downward trend, and by 1931, there was a greater average decrease in cholera deaths in towns which received major investment compared to towns which did not. Ultimately, the results reinforce that towns which received major investment were counterfactually better off in terms of change in deaths by cholera than towns which did not.

Figure 9. Graphical representation of diff-in-diff estimation



Note: Plot points derived from panel dataset and Table 5
Source: *Annual Report of the Sanitary Commissioner for Bengal 1906-1928; Bengal Public Health Report 1929-41.*

3.3 Endogeneity concerns

In summary, my analysis has demonstrated that gradual increases in investment in major waterworks significantly lowered the death rates by cholera in towns across Bengal's 5 divisions, and that smaller gradual increases in investments in drainage and sewerage works had no significant effect. I also show that towns which experienced major sanitary developments in clean water provision through investments in waterworks were counterfactually better off in terms of the rate of change in cholera deaths than towns which did not experience major development. However, two factors may challenge the soundness of my econometric estimations and the conclusions drawn from it.

Firstly, a variable which I have not accounted for in my estimations is the potential effect of changing attitudes towards sanitation in 20th century India. Changes in individual behaviours due to the widespread acceptance and diffusion of European sanitary standards and medical knowledge like the germ theory of disease would have had helped the alleviation of cholera and other waterborne contagions. However, this theory was not accepted by India's public health authorities until 1890, let alone internalized by individuals. Once these ideas were accepted, policies were formalized to try and propagate public health awareness through compulsory hygiene education and health propaganda. The absence of time fixed effects in section 3.1's regression specification does not allow for the accounting of such external health confounders. However, a significant time-lag occurred between the state's intention to promote hygiene awareness and the actual implementation of such measures. In the early 1920s, health exhibitions were held intermittently and only in major cities at first.[50] It wasn't until 1931 when reports refer to a 'sanitary conscious' forming in society in response to health propaganda.[51] As cholera deaths were already on the decline, and major sanitary works were well underway, the reduction in cholera deaths that happened prior to 1931 was unlikely to be primarily caused by an increase in hygiene awareness. Finally, incorporating time fixed effects in our model would not have controlled for changes in behavioural hygiene at the individual level which would necessarily vary across time and space. Therefore, the effect of the changes in individual behaviours on cholera deaths are expected to be marginal, especially in the period I have examined.

There are other legitimate endogeneity concerns that my econometric model may be susceptible to, such as reverse causality. It is plausible that in the 20th century, one of the stimuli for major sanitary investments was cholera deaths. Local governments were more likely to respond with investments towards major waterwork developments in the towns which suffered greatly from waterborne diseases. In fact, figure 8 demonstrates this, as towns which received investment suffered on average more deaths by cholera than towns which did not at the start of the period. It is true that the intensification of disease outbreaks and epidemics, which were exacerbated by indigenous hostility toward state intervention, and the prolonged inaction of the state, reached a boiling point and

[50] Department of Public Health, Bengal (India), *Bengal Public Health Report, 1921,* (Calcutta: The Bengal Secretariat Book Depot, 1923), 35.
[51] Department of Public Health, Bengal (India), *Bengal Public Health Report, 1931,* (Calcutta: The Bengal Secretariat Book Depot, 1933), Chapter X, 99.

culminated with the state taking bolder steps in preventing disease through investments in major sanitary developments.[52]

However, there is quantitative evidence to mitigate these concerns and show that the increases in major sanitary investments were mainly exogenous. To show this, I have taken the same regression specification as model (2) replacing the dependent variable with the change in real investment in town i in year t, and the regressor of interest with different variables which capture a lagged response to previous deaths rates, or changes to death rates. If coefficients of these 3 variables are positive, relatively large, and statistically significant, reverse causality would be confirmed. However, the results from table 6 show no significance for any of the 3 specifications tested, thus removing any concerns over reverse causality in the period examined. It is possible that the initial impetus for authorities to take more decisive actions in disease prevention was the escalating death tolls and the increasing prevalence of epidemics. However, between the years 1913 and 1931, when the government had already initiated plans to enhance India's sanitation infrastructure, allocations of investment were not reactive to changes in cholera deaths. Overall, concerns over reverse causality may persist, but I believe my results in table 6 have helped alleviate them to some extent.

[52] Arnold, *Cholera and Colonialism in British India*, 149

Table 6. Testing for reverse causality between cholera death rates and real investments in waterworks

Variable	**Real investment in waterworks**		
	(1)	**(2)**	**(3)**
$\Delta Cholera_t$	-0.0306 (0.0399)		
$Cholera_{t-1}$		0.00703 (0.0743)	
$\Delta Cholera_{t-1}$			-0.0189 (0.0333)
Population	0.000121* (0.0000538)	0.000121* (0.0000549)	0.000120* (0.0000543)
Rainfall dummy	Yes	Yes	Yes
Natural shocks dummy	Yes	Yes	Yes
Town fixed effects	Yes	Yes	Yes
R^2	0.024	0.023	0.023
N	744	744	744

Note: dependent variable is the change in real investment between year t-1 and year t as defined in the text. I have taken the log values of real investments to adjust the coefficients to the scale of cholera death rates per mille. Independent variables are the change in cholera death rate between year t-1 and t, the cholera death rate in year t-1, and the change in cholera death rate between year t-2 and t.1. Robust standard errors are in parentheses. ***Significant at the 0.1% level. **Significant at the 1% level. *Significant at the 5% level.
Source: See Table 4

4. Conclusion

The 20th century is often described as a transformative period for South Asia, marked by significant political, economic, and social changes. One area of progress during this period that is often overlooked is the significant improvements in public health. The standards of sanitation in India transformed with increased state intervention and investment. Rather than focusing on the significant political changes which largely characterize the region in this period, this paper has explored the fundamental micro-changes which had personal impacts on the lives of Indian citizens: the sanitary revolution and the decline in disease mortality. Moreover, I have explored the medical theory that links clean water and waste disposal to waterborne diseases, using Bengal as a historical account.

I began by reviewing the significant changes which occurred between the 19th and 20th century, most importantly, the realization of the state to intervene with robust disease prevention schemes, through the construction of waterwork, drainage, and sewerage systems. I assembled and drew from an original dataset, composed from over 30 years of public health and sanitary reports which outline investment levels, cholera deaths, and a host of other variables. This has allowed me to assess the role that investments played on mortality reversal in India, using reductions in cholera deaths rates as the main mechanism.

I have found that between the years in which major investment in waterworks, drainage, and sewerage occurred (1913 to 1931), waterworks had a greater effect on cholera deaths than drainage and sewerage. I have tried to validate my results on waterworks further comparing its effects between towns which received investment and towns which did not. My results showed that the change in cholera deaths dropped by 37.42 deaths more than it would have had it not been for investment, thus, confirming that towns which received investment were counterfactually better off. Finally, given that total major investment in waterworks increased by 153% between 1913 and 1931 (Figure 5), and average cholera deaths per mille in Bengal reduced by 0.28 for the same period (Table 1), we can calculate the total effect of waterwork investments. We find that for the whole period, the effect of waterworks investments made up 17% of the total provincial fall in cholera mortalities. I have lastly addressed potential endogeneity issues that could affect my results, which I believe I have partially mitigated these.

Overall, my findings support the claim that progressive improvements in sanitary infrastructure through investments in waterworks played an important role in South Asia's containment of waterborne diseases and mortality reversal. I have provided a robust account of the connection between clean water provision and waterborne disease mortalities. My method could be expanded and applied to other regions to corroborate this connection further. By analyzing state investments, I have shed light on the British colonial administration, and their approach to public health in India, demonstrating that their increased intervention through disease prevention schemes yielded positive effects at the local level. The study could be built upon further by analyzing the possibility that sanitary investments had multiplier effects, on other diseases and indicators of health, and possibly on factors beyond health.

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