

The Late Decline of Seasonal Diarrhoeal Mortality: Temperature and Urban Sanitation in England and Wales, 1891–1930

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During the late nineteenth and early twentieth centuries, England and Wales witnessed a significant decline in mortality from faecal–oral diseases such as typhoid, cholera, and dysentery. However, infant diarrhoeal mortality showed a more complex trajectory, with a particularly strong seasonal component. In many industrialising societies, infant diarrhoea mortality peaked in the summer months, with hot weather exacerbating transmission through contaminated food, water, and insect vectors such as flies. While public health historians have emphasized the role of sanitary infrastructure, such as filtration, chlorination, sewage treatment, and milk regulation, in shaping disease decline, evidence from US cities from early twentieth century suggests that municipal interventions alone cannot fully explain the waning of summer diarrhoea mortality around 1920s (Anderson et al. 2020).

London data for 1866–1965 show that the strong effect of warm weather on infant mortality weakened and effectively disappeared after the First World War (Hanlon et al. 2021). This raises broader questions about how the relationship between temperature and infant diarrhoeal mortality changed in other large towns, and what mechanisms underpinned this shift.

The aim of this paper is to address the question of the late decline in infant diarrhoeal mortality by examining two main aspects. First, we analyse the disappearance of large peaks in summer diarrhoeal deaths, which represents the most striking change in the mortality trend. Specifically, we investigate how the relationship between temperature and mortality changed in England and Wales during the early decades of the twentieth century. We also assess to what extent variations in mortality improvements between large towns provide evidence that public health interventions and differences in sanitary infrastructure contributed to the decline in infant diarrhoeal mortality. What alternative mechanisms, such as changes in infant feeding practices, might have reduced vulnerability to diarrhoeal infections?

Data and Methods

We compiled a new dataset linking mortality, demographic, socio-economic and weather data for English and Welsh towns. Mortality information came from the *Weekly Returns* for 1890–1930, which was used to estimate weekly infant mortality rates and deaths from diarrhoea and enteritis per 1,000 births. Due to changes in town coverage over time, we constructed two separate analytical samples. The first sample covers the years 1893–1930 and includes 31 towns observed each week throughout this period. This dataset comprises 1,400,221 infant deaths and 265,156 diarrhoeal deaths across 2,033 weeks. The second sample spans a shorter period, from 1903 to 1930 (1,461 weeks), but includes a broader set of 74 towns. It contains 1,300,878 infant deaths and 235,532 diarrhoeal deaths.

The weather data used in this study are drawn from the *Met Office Integrated Data Archive System (MIDAS)*, which provides daily maximum and minimum temperature, as well as total daily precipitation, from a network of weather stations across the UK dating back to 1853. Over time, the number of UK weather stations reporting daily temperature data increased from over 10 in the 1890s to around 60 by 1930. This means over our observation period on average, 30 weather stations provide daily temperature data. To construct weekly measures of mean and maximum temperature from these daily records, we use the location of the town and the

weather station to match the closest weather station in each year with full observations to towns in our analytical sample.

In addition, we compiled demographic and socio-economic data from individual-level census datasets for the years 1891-1911. For 1921 and 1931¹, we rely on occupational data extracted from published reports by the Office for National Statistics (ONS), accessed via NOMIS (NOMIS 2025)². From these data, we construct key occupational indicators for each town, including the share of women working in textile industry, and the share of men working in mining, transport, and horse-based transport. All the occupational variables are normalised by the working age population. To obtain annual estimates between census years, we apply linear interpolation.

The analytical approach uses two-way fixed effect models:

$$\log(IMR_{t,y,w}) = \sum_j \theta_j \text{TEMP}_{t,y,w,j} + X_{ty}\beta + Xprcp_{tw}\beta + \alpha_{t,m} + \mu_{y,m} + \varepsilon_{t,y,w}$$

where $IMR_{t,y,w}$ is the weekly infant mortality rate in each town (indexed by town t , year y , and week w).³ The vector of control variables are X_{ty} and $Xprcp_{tw}$. The first one includes annual demographic and socio-economic controls, whereas the latter captures weekly cumulative total precipitation in each town. We distinguish between total precipitation in the same week, two week total, three week total, and four week total. $\alpha_{t,m} + \mu_{y,m}$ are sets of town-by-month and year-by-month fixed effects. Our empirical strategy follows previous similar approaches to estimate mortality-temperature relationship (Barreca et al. 2016; Hanlon et al. 2021).

The key variables of interest are the temperature measures, denoted as $\text{TEMP}_{t,y,w,j}$, which capture the number of days in a given town-year-week when the daily mean or maximum temperature falls within the j -th of six temperature bins: <0 °C, $0-4$ °C, $5-9$ °C, $10-14$ °C, $15-19$ °C, and >20 °C. The $10-14$ °C range is used as the reference category. More than 60% of days fall between $5-14$ °C, while days with mean temperatures above 20 °C are relatively rare, accounting for only about 1% of the sample. Following previous work, we estimate lag models to capture not only the contemporaneous effects of temperature on child survival but also potential delayed impacts.

To explore how local public health provisions and the disease environment may mitigate the temperature-mortality relationship and its evolution over time, we estimate separate models that focus on the upper and lower extremes of the temperature distribution. In these models we use three temperature bins: <5 °C, $5-19$ °C, and >20 °C, with the middle range ($5-19$ °C) serving as the reference category.

¹ Great Britain. Census Office. (1934). *Census of England & Wales, 1931.: Occupation tables*. London: H.M. Stationery Off. [Print by C. Tinling & Co., Ltd.].

² 1921: https://www.nomisweb.co.uk/sources/census_1921_cr, table CR16i;

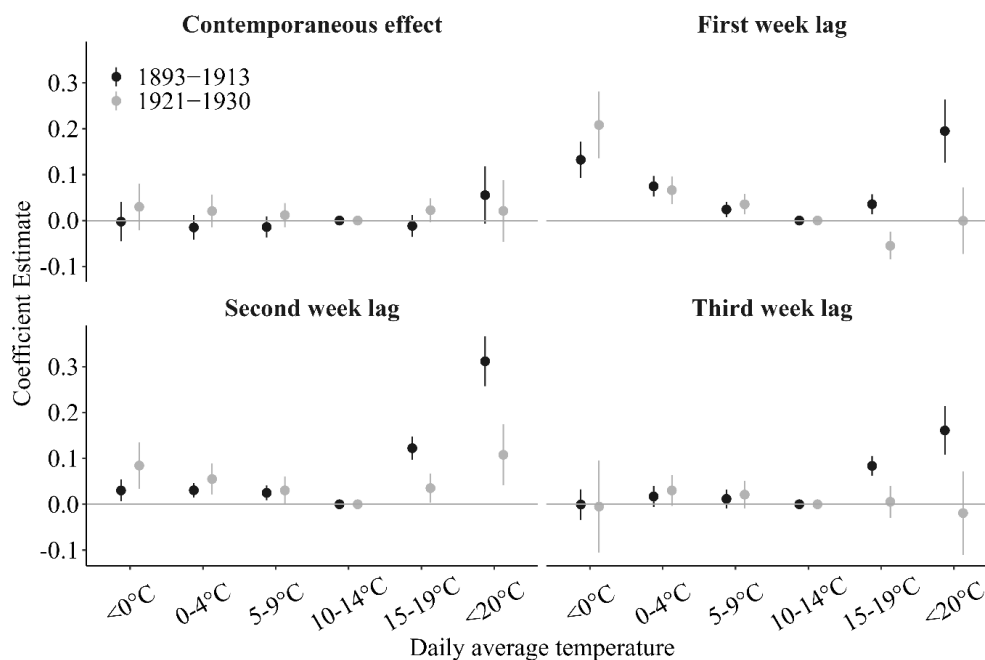
1931: https://www.nomisweb.co.uk/sources/census_1931_bulk, table OT16.

³ All the main models use the infant mortality rate as the outcome variable rather than the diarrhoeal mortality rate. This choice helps to avoid excessive zeros in the outcome variable. Because of the high granularity of the data, many towns in the sample recorded no diarrhoeal deaths in many weeks of the year. In contrast, most towns experienced at least some infant deaths each week.

Preliminary results

Our findings in Figure 1 reveal a clear disappearance of the summer diarrhoeal mortality peak during the first decades of the twentieth century. Strong lagged effects, especially first and second week lag, of high summer temperatures on infant mortality persisted in large towns until the First World War, after which the temperature–mortality relationship weakened substantially.

Figure 1. The impact of extra day below or above reference temperature range (10-14°C) on infant mortality, 1893–1913 and 1921–1930.



Notes: 1893–1930 sample includes 31 towns. Model coefficients are estimated from two separate regressions. The regressions include demographic, precipitation and socio-economic control variables and town-month and year-month fixed effects. The confidence intervals refer to 5% significance levels. The standard errors are clustered at the town level.

For a smaller sample of 22 towns we have collected annual estimates of flush toilet provision in each town from Medical Officer of Health (MOH) reports. Flush toilets were an incipient sanitary technology spreading across towns over this period. Table 1 indicates that poor toilet facilities intensified mortality responses to high summer temperatures in the pre-WWI period, consistent with the role of inadequate faecal disposal in sustaining transmission. However, improvements in water supply and sewerage alone do not fully account for the decline. Interaction tests suggest that sanitary provision explains part of the reduction in sensitivity, but not the timing of the sharp post-WWI shift.

Alternative explanations for the decisive decline in infant diarrhoeal mortality may lie in changes to infant feeding practices and the growing availability of new food products, such as dried milk, in the aftermath of the First World War. Fildes (1998) documented a marked shift away from the use of long-tube bottles (often referred to as “killer bottles”) in Norwich between 1908 and 1922. Similar patterns are visible in Coventry (MOH reports), where dried milk

products for infant feeding gained particular popularity after 1916, and long-tube bottles had virtually disappeared by the early 1920s.

Table 1. The mitigating impact of sanitary infrastructure or local occupational structure on infant mortality

	Log Infant Mortality Rate		
	1893-1930	1893-1913	1921-1930
Adoption of flush toilets			
Below 5°C x flush toilets %	0.0007*	0.0001	-0.0002
5°C to 20°C x flush toilets %	ref.	ref.	ref.
Above 20°C x flush toilets %	-0.003**	-0.0017*	-0.0047
Town-month FE	Yes	Yes	Yes
Year-month FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
Number of towns	20	20	20
Observations	40,592	21,876	10,420

Notes: 1893–1930 sample includes 31 towns. *p<0.10, **p<0.05, ***p<0.01

Conclusion

The decline in infant diarrhoeal mortality in England and Wales between 1890 and 1930 reflects a complex interplay of environmental, infrastructural, and behavioural factors. While public health investments in water, sanitation, and milk supply improved baseline conditions, they cannot by themselves explain the abrupt weakening of the summer temperature–mortality relationship after WWI. Instead, changing infant feeding practices played decisive roles.

This analysis highlights the importance of integrating climatic, infrastructural, and behavioural perspectives in understanding historical mortality transitions. It also underscores that mortality declines may not follow uniform trajectories across causes of death: while waterborne diseases declined steadily with sanitary reforms, the waning of infant diarrhoeal mortality was shaped by a distinctive interaction between heat, hygiene, and infant care practices. These findings contribute to broader debates about the drivers of health improvements in industrial societies and the historical resilience of populations to environmental stressors.

References

- Anderson, D. M., Rees, D. I., & Wang, T. (2020). The phenomenon of summer diarrhoea and its waning, 1910–1930. *Explorations in economic history*, 78, 101341.
- Barreca, A., Clay, K., Deschenes, O., Greenstone, M., & Shapiro, J. S. (2016). Adapting to climate change: The remarkable decline in the US temperature-mortality relationship over the twentieth century. *Journal of Political Economy*, 124(1), 105–159.
- Fildes, V. (1998). Infant feeding practices and infant mortality in England, 1900–1919. *Continuity and Change*, 13(2), 251–280.
- Hanlon, W. W., Hansen, C. W., & Kantor, J. (2021). Temperature, disease, and death in London: analyzing weekly data for the century from 1866 to 1965. *The Journal of Economic History*, 81(1), 40–80.