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RESEARCH ARTICLE

The Last Nationwide Smallpox Epidemic in the Netherlands: Infectious Disease and Social Inequalities in Amsterdam, 1870–1872

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Abstract

The complex relationship between the history of infectious diseases and social inequalities has recently attracted renewed attention. Smallpox has so far largely escaped this revived scholarly scrutiny, despite its century-long status as one of the deadliest and widespread of all infectious diseases. Literature has demonstrated important differences between rural and urban communities, and between cities, but has so far failed to address intra-urban disparities due to varying living conditions and disease environments. This article examines the last nationwide upsurge of smallpox in the Netherlands through the lens of Amsterdam's 50 neighborhoods in the period 1870–72. We use a mixed methods approach combining qualitative spatial analysis and OLS regression to investigate which part of the population was affected most by this epidemic in terms of age and sex, geographic distribution across the city, and underlying sociodemographic neighborhood characteristics such as relative wealth, housing density, crude death rate, and birth rate. Our analyses reveal a significant spatial patterning of smallpox mortality that can largely be explained by the existing social environment. Lacking universal vaccination, the smallpox epidemic was not socially neutral, but laid bare some of the deep-seated social and health inequalities across the city.

Keywords: smallpox; epidemics; social inequality; mortality; vaccination; urban

Introduction

As the world grapples with the COVID-19 pandemic, the history of infectious diseases and its complex relationship with social inequalities has attracted renewed attention. Smallpox has so far largely escaped this revived scholarly scrutiny, despite its century-long status as one of the deadliest and widespread of all infectious diseases. The current escalation of the global monkeypox outbreak may well heighten interest in its historical forebearer, closely related as the viruses are. Transmitted by airborne droplets or the pus from pustules of an infected person (Crosby 2008;

Milton 2012: 1008–9), first symptoms of smallpox would often consist of muscle and joint pain, fatigue, high fever, nausea and vomiting, after which the virus would attack the skin cells, resulting in a rash that would eventually cover the entire body. In many cases, the rash developed into blisters, which turned into scabs that left scars. While the course of illness from monkeypox appears to be comparatively mild, levels of mortality from smallpox were high: in its many names such as "variola" or "speckled monster," smallpox killed around 25–40 percent of its victims (Dobson 2015: 277–98). A key factor was that anyone who was infected by smallpox and survived the ordeal thereafter possessed lifelong immunity to the disease. This resulted in a large part of the European adult urban population possessing substantial immunity, while those unprotected by previous infection or vaccination, such as children and migrants from the countryside, were susceptible. Before the era of widespread vaccination against smallpox, it would often erupt as a substantial epidemic at least once in a lifetime.

Following widespread and intensified immunization and surveillance around the world, the World Health Organization declared smallpox eradicated in 1980. Smallpox therefore became known as the first, and currently only, infectious disease to have been effectively stamped out, making it one of the most profound public health successes in history. The number of susceptible individuals has grown since then due to the cessation of routine vaccination. Scholars like Nishiura therefore analyze the disease to counter its use as a possible future threat of bioterrorism (Nishiura et al. 2008; Nishiura and Kashiwagi 2009). Rimoin et al. (2010) and Reynolds and Damon (2012) also discuss the use of smallpox vaccines to curtail the spread of other communicable Orthopoxvirus-associated illnesses such as monkeypox amid waning immunity against smallpox. The history of the fight against smallpox also illuminates how countermeasures led to distinctive styles of public health, to vaccination programs, (religious) anti vaccination campaigns, and increased state control (Hopkins 2002; Foege 2011; Williams 2011; Bennett 2020). Krylova and Earn (2020) as well as Davenport et al. (2018) provide evidence that changes in epidemiological patterns may be correlated with control interventions and public health policies in cities. Port cities in particular were forerunners in this regard (Mortimer 2008; Brabin 2020).

In our study, we are interested in how the disease itself spread geographically across and within a city and its population, and if individuals living in particular neighborhoods were more at risk compared to others. Regional differences in the spread and impact of smallpox have already been examined by various other historical studies (Duncan et al. 1993; Sköld 1996; Duncan and Duncan 1997; Davenport et al. 2018; Rafferty et al. 2018), but we ask the question how inequalities were expressed in a demographic and spatial sense in one specific city, namely Amsterdam. Other epidemics such the bubonic plague and the Spanish Flu are being studied through the lens of social inequalities (Mamelund 2006; Bengtsson et al. 2018; Alfani 2021; Fourie and Jayes 2021), but smallpox has so far not received such scrutiny. This may in part be due to the idea that smallpox struck lower and higher social classes fairly equally due to its mode of transmission, namely air and close personal contact (Snowden 2019: 97–101). Moreover, smallpox was a type of disease that was insensitive to the nutritional status of the host (Rotberg and Rabb 1985).

There are also reasons to assume that socioeconomic status, living conditions, and disease environment did affect patterns of smallpox mortality. After all, as a "social disease par excellence" (Perrenoud 1975: 239), higher living standards, lower density dwellings, and more opportunities to keep distance from infected people and places could reduce the impact of an epidemic (Rutten 1997: 141). Furthermore, because smallpox may have also spread through personal contact with contaminated clothing, the susceptibility to infection was heightened among certain predominantly lower-class occupations such as launderers (Hardy 1993: 140; Crosby 2008: 1009). Our article argues that the lack of attention for this "deputy grim reaper" (Dribe and Nystedt 2003: 9) is undeserved: not only because smallpox was a highly lethal disease, but also because it allows us to shed important light on the role of spatial and social inequalities in the impact of epidemics across society.

The last nationwide upsurge of smallpox in the Netherlands is examined through the lens of the city of Amsterdam in the period 1870–72 for two reasons. First, it allows us to get an in-depth view of how an epidemic impacted a large city with a diverse population living in varying social, economic, and demographic settings and circumstances. Second, unique data on causes of death are available, which we combined with other sources that provide sociodemographic information on each of Amsterdam's 50 administrative neighborhoods. Our dataset allows us to scrutinize which parts of the population within Amsterdam were affected most by the smallpox epidemic in terms of age, sex, and geographic distribution across the city. It makes it possible to not only study the impact of the disease in terms of mortality patterns, but also reveals the relevance of social inequality on an intra-urban level.

Background: Smallpox and social inequality

Historical relationships between mortality and socioeconomic status, living conditions, and the disease environment remain poorly understood. Link and Phelan (1995) and Phelan et al. (2010) argued that socioeconomic differentials in mortality have been more or less constant over time by proposing the theory of fundamental social causes. It was founded on the assumption that those who had greater access to social and economic resources would have a mortality advantage in every context. Still, an important distinction should be made between the underlying mechanisms causing lower mortality on the individual and contextual level: while contextual factors reflect the effect of the environment in which people live, such as neighborhoods, individual factor refers more to how income, lifestyle, social networks that influence health (Phelan et al. 2010). Despite the fact that recent adjustments of this theory suggest the precise mechanisms might vary per disease and across time, it still could result in a persistent association between health differences between individuals based on living conditions and disease environments. In other words, the specific temporal context is important as it determines the precise association between socioeconomic status and (cause-specific) mortality risks (Clouston et al. 2016).

So far, for the period before the twentieth-century longitudinal data across Western and Southern Europe, the US and Canada has not provided definitive conclusions about the association between mortality and social class as measured through income, wealth, or occupational status (Antonovsky 1967; Bengtsson and van Poppel 2011; Bengtsson et al. 2018). For example, while Debiasi (2020) and Dribe and Karlsson (2022) suggest that in Sweden a "social gradient" in mortality only emerged from the twentieth century onward, social differences in mortality did already exist in the Netherlands for certain age groups before the twentieth century (Van De Mheen et al. 1996; van Poppel and Mandemakers 1997; Hoogerhuis 2003; van Poppel et al. 2009; Schenk and van Poppel 2011; Riswick 2018; Mourits 2019). Better hygiene, access to clean drinking water and sewerage, and class-based differences in vitamin intake most likely played an important role in determining differences in general mortality risks. Moreover, human interventions and public health policies could differently affect the relationship between socioeconomic status and cause-specific mortality patterns on an individual and contextual level across time and space (Clouston et al. 2016).

Examinations of the relationship between socioeconomic status and smallpox mortality are equally inconclusive. For instance, a heated debate has erupted over the relationship between smallpox and height as an indicator for living standards: Voth and Leunig (1996, Leunig and Voth 2001) and Quanjer and Kok (2021) contend that smallpox caused stunting, while Razzell (1998, 2001), Heintel and Baten (1998) and Vervaeke and Devos (2018) found no such effect. These discordant outcomes suggest that the association between smallpox on height actually varied by location and time period, most likely because overcrowding in urban communities was closely associated with height and smallpox (Oxley 2003, 2006). The same may be true for smallpox mortality between social groups. Hardy (1993: 133–34) noted a striking contrast between smallpox death rates between the poor and better-off class in nineteenth-century London. For this she relied on contemporary observations by medical doctors analyzing the social composition of 912 smallpox deaths occurring between 1871 and 1881. Among the better-class group a death rate of 0.2 per 1,000 living was observed, and 1.76 among the poor. Interestingly, these doctors attributed this disparity in mortality not only to the worse social conditions such as not having the means of isolation in their homes, but also to the "social and domestic habits of the poor" such as visiting each other indiscriminately and not avoiding infected houses and persons like the better classes as important factors in the spread among these segments of society. Hospital records from Boston's epidemic of 1901–3 reveal that patient survival from smallpox depended on individual characteristics such as age, disease severity and being vaccinated, while sex, birthplace and race did not seem important (Albert et al. 2002).

In his seminal work on smallpox in the eighteenth- and nineteenth-century Netherlands, Rutten (1997) argued that there may well have been a socioeconomic aspect to who ended up dying from smallpox. Based on the taxes levied on burials in Amsterdam between 1731 and 1800, he calculated that the excess mortality in the period before vaccination increased down the wealth ladder (Rutten 1997: 137–38). His work furthermore indicates that religious or cultural affiliation was a factor of importance in survival chances during the smallpox epidemic of the 1870s. A wide range of studies have suggested that Jewish populations experienced reduced overall infant mortality risks (Verdoorn 1965: 62–68; Blom and Cahen 2017; Ekamper and van Poppel 2019; Riswick et al. 2022), but Rutten demonstrated that this was also the case for smallpox epidemics (Rutten 1997: 153). Better hygiene practices as well as Jewish parents' willingness to vaccinate their children are believed to have been instrumental in achieving this mortality advantage. This example of Dutch Jewish communities highlights how aggregated information about city-wide vaccination levels does not do justice to the differentiated impact of the smallpox epidemic across the urban landscape. Since universal uptake across the Amsterdam population was lacking, factors such as population density, crowding per house, and birth rates in different parts of the city seem pertinent (Rutten 1997: 131, 141). These are examples of the many ways in which social inequalities also operated through the residential environment (Reid 1997).

Previous research has already suggested that location could be associated with large differentials in mortality. Rafferty et al. (2018) noted the geographical variation in smallpox activity across England and Wales between 1920 and 1935, attributing the varying intensities to series of sociodemographic factors impeding disease control. For the Netherlands from the sixteenth-century onward, Rutten (2011) also pointed to urban–rural discrepancies in smallpox mortality. Their works echo broader findings from historical demography that conclude that environment, or "place," had a pronounced effect on mortality, pointing to important differences between urban and rural environments as well as regional disparities (Reid 1997; Razzell and Spence 2006; van Poppel et al. 2009; Edvinsson and Lindkvist 2011; van den Boomen and Ekamper 2015; Van Rossem et al. 2018; Jaadla et al. 2020).

Levels of aggregation of mortality data generally do not allow intra-urban differences to be taken into account, even though there is important evidence suggesting that the impact of epidemics was not distributed equally across its inhabitants in the urban landscape. It is an important reason for our study to scrutinize the social, residential, and disease environment on a neighborhood level within one city. Cities were no homogeneous blocks of social conditions. It is therefore important to scrutinize those affected by smallpox in relation to their position in the social, residential, and disease environment. Offering neighborhood level data both on mortality and various sociodemographic characteristics, the city of Amsterdam therefore presents an interesting case study to investigate in much more detail how smallpox developed in a specific city, who it affected, and in what socio-spatial context. We assume that living conditions and disease environments of residential areas were differentially distributed among the population and that ones' place in the urban landscape affected mortality. In short, through the analysis of Amsterdam's neighborhoods, we shed more light on intra-urban social differences in smallpox mortality otherwise averaged away by investigations of city-wide or regional-level data.

Historical context: Development and contemporary views of the smallpox epidemic in the Netherlands

The last national epidemic outbreak of smallpox in the Netherlands occurred in the period 1870–72 and was part of a worldwide pandemic (Rutten 1997: 193). It is not only interesting because it was the last big outbreak for this dreaded disease, but also because it was the first that was scientifically studied by contemporaries, resulting in much more documentation being available compared to previous outbreaks. A total of 20,575 people died from smallpox in the Netherlands during the early 1870s: 60

percent of whom were younger than 10 years old. This number also caused the general mortality to be about 4 percent higher compared to previous years (Rutten 2011: 185).

Synthesising works on the history of smallpox have explained the large-scale impact of the 1870s outbreak by pointing to a combination of coincidences (Rutten 1997; Hopkins 2002). For instance, the virulence seems higher compared to earlier smallpox outbreaks. Biraben (1979) suggested that this may be the result of evolution of the virus, though Fenner (1988) argued that several variants of the smallpox virus existed over the world and a more virulent one was imported. Historical developments, such as increased urbanization and global connectedness through railway transportation, also caused society to be more susceptible. Furthermore, by this time there were only a few people left who had been born before 1800; a period in which smallpox epidemics had been more frequent and those who survived became immune. Combined with decreased vaccination efforts during the 1860s, this rendered the population in most societies more vulnerable than before, especially in densely populated cities (Hopkins 2002: 88–93). Lastly, the French–German war also played an important role. For example, Dutch citizens were repatriated and the Dutch army was mobilized because of political unrest. This caused an additional movement of a large number of people, thereby helping the virus to spread as well (Rutten 1997: 381–82).

Unsurprisingly, the first smallpox cases in the Netherlands were reported in the National Military Hospital (*'t Rijks Militair Hospitaal*), which also became one of the places that caused spreading of the virus within the country (Carsten and van Overbeek de Meijer 1875). Figure 1 shows the number of people who died from smallpox in the Netherlands for several major cities across the Netherlands, adjusted for population size. It demonstrates that from the last month of 1870 onward the number of deaths from smallpox increased rapidly. In a report discussing the epidemic the health inspectors wrote: "In October 1870 it became clear that we would not succeed to prevent the development of an epidemic, which should not be a surprise when seeing how carefree and careless people acted, and how many cases were concealed by military authorities and civilians" (Carsten and van Overbeek de Meijer 1875: 13). The Western part of the Netherlands (cities such as The Hague, Utrecht, and Rotterdam) experienced the smallpox epidemic first, and in general most smallpox deaths occurred in 1871. In 1872 a smaller second wave of smallpox deaths occurred in other parts of the country (in cities such as Nijmegen), although this was concentrated particularly in the first months of the year.

Figure 1 also demonstrates that significant differences existed between Dutch cities. While death counts were not dissimilar, smallpox mortality per 1,000 inhabitants was notably lower in Amsterdam than in The Hague, Rotterdam, and Utrecht. Amsterdam's proportionally moderate death toll during the epidemic of 1870–72 was not necessarily self-evident. From the 1860s onward, the city experienced a significant economic revival due to the fast-growing capital market, the flow of colonial products through Amsterdam's staple market, and the increase of capital-intensive industrial companies such as sugar refineries, beer breweries, and gas factories (Knotter 1991: 238). The rise of employment opportunities attracted a steadily increasing number of migrants to the city, with a peak during

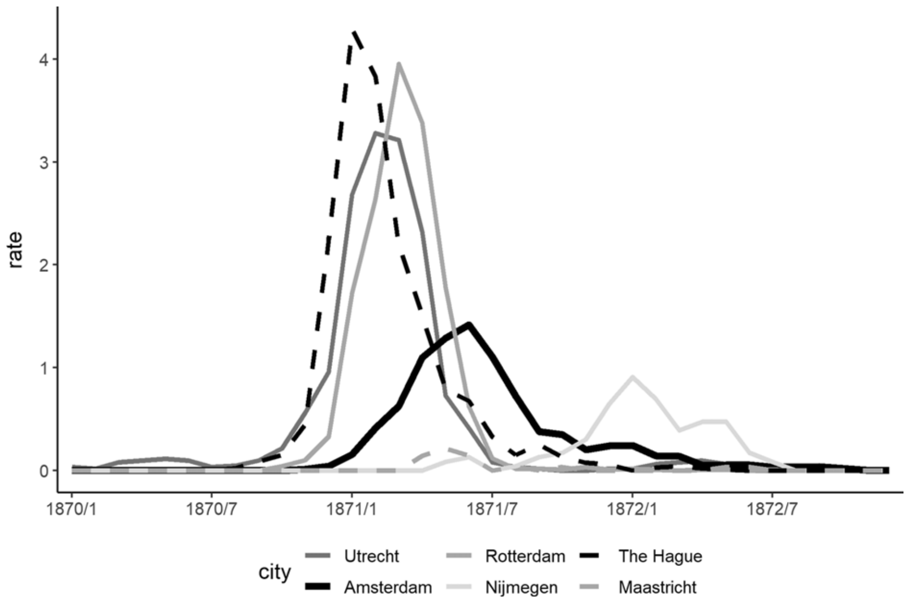

Figure 1. Number of smallpox deaths per 1,000 inhabitants in major cities in the Netherlands, 1870–73.

the 1870s and 1880s (van Zanden 1987: 78–79). Combined with the birth surplus, Amsterdam's population swelled considerably during this period. Because expansion of the housing supply lagged behind, living conditions in the city deteriorated substantially (Diederiks 1982: 116). With a modern sewage system still decades away and large parts of the working-class neighborhoods still devoid of a connection to the slowly expanding water supply infrastructure, overcrowding further aggravated the already precarious sanitary conditions in many parts of Amsterdam (Aerts 2006: 222, 234; de Rooy 2006: 371–73). In sum, Amsterdam appeared to have had the odds stacked against it on the eve of the epidemic.

Contemporaries attributed this apparent incongruity to the effective and swift action taken by Amsterdam's City Council to establish a special committee to fight the epidemic: "this committee, strongly supported by the city government, has endeavored to curb the prevalence of disease as much as possible by appropriate measures during the whole epidemic" (Carsten and van Overbeek de Meijer 1875: 53). Measures that were implemented in Amsterdam included the suspensions of planned fairs, the closing of schools, increasing ventilation in homes, cleaning and disinfecting houses of those who died from smallpox, the marking of contaminated houses, and preventing the movement of infected people. Other city governments had taken similar measures, though not all implemented them as forcefully as Amsterdam (Carsten and van Overbeek de Meijer 1875: 55).

Another important measure was an increase in vaccination efforts. When the first smallpox sufferers were brought into the *Buitengasthuis*, a hospital located just outside of the city of Amsterdam, a vaccination program was set up as quickly as possible to vaccinate or revaccinate staff members as well as "a number of sufferers from chronic diseases" (Huet 1880: 380). Special attention was furthermore paid to informing the poor about the emerging epidemic and the vaccination campaigns, for example through news items in local newspapers. On Thursday 8 December 1870 the directors of the Amsterdam Society for the Promotion of Cowpox Vaccinations for the Poor (*Amsterdam Genootschap ter Bevordering der Koepokinenting voor Minvermogenden*) published a newspaper article to warn the population about the upcoming outbreak, and informed them about where they and their children could get vaccinated. They emphasized that vaccination was free of charge and that for "the poor, who have their children vaccinated at the Town Hall, a small monetary allowance for absenteeism, is provided by the Society" (van Hees and D'Ailly 1870). Moreover, the city government had already introduced the requirement of a smallpox vaccination certificate (*pokkenbriefje*) before children were allowed to enroll in schools. In contrast to Rotterdam and Den Haag, no exception was made for "special" schools of specific religious denominations (Rutten 1997: 273–78).

Newspaper articles from the time reveal the authorities' attempt to contain the effects of the epidemic, but also demonstrate that people needed to be convinced to get vaccinated. Many news items tried to convince their readers that vaccination could prevent death from smallpox, often by providing emotional examples. One such example detailed the misfortunes of a family in which only some children were vaccinated and others were not:

> "In a household of six children (. . .) all enjoyed blooming health until 15 days ago. They were sweet and well-fed children. There the smallpox poison enters the home and seeks its victims (. . .) In a few days the youngest child died, terribly deformed. The 6-year-old boy died, in painful suffering; the third non-vaccinated child was heavily affected. The remaining three vaccinated children, sleeping in the same room, were perfectly well, and the smallpox poison has not been able to disturb the health of these little creatures" (Algemeen Handelsblad 1871a).

Furthermore, these newspaper articles often focused on explaining why a vaccination was not always successful in preventing contagion – because revaccination was necessary, the vaccine was not effective anymore, or the vaccination itself was done incorrectly – to convince people that in the majority of cases vaccination would make a difference. Some news items even strongly advocated against religiously motivated vaccination refusal, in one instance contemptuously suggesting that the objection that "one should not conceal God's image by beastly contamination" would be suitable for those who would also "try to stretch their lives through a miracle, or, as in Cockaigne, by letting roast pigeons fly into their mouths" (Algemeen Handelsblad 1871b). News items such as these shed some light on vaccination hesitancy among the population and how medical and governmental authorities worked together to fight it (Snowden 2019: 107–10).

Despite all efforts, there was no universal vaccination uptake. Between 1820 and 1860 only about half of the population was vaccinated, almost no one was revaccinated, and vaccination efforts declined during the 1860s. Table 1 demonstrates that Amsterdam ranked rather low on the vaccination index of the major cities in the Netherlands: only Rotterdam did worse. In Amsterdam, on average only 43 out of 100 infants who survived until their sixth month of life were vaccinated. Around the

Table 1. Vaccination index in major cities in the Netherlands, 1820–80

	1820–60	1820	1840	1860	1880
Rotterdam	34.4	19.4	41	42.4	97.1
Amsterdam	43.3	48.7	51	30.3	70.1
Leiden	45.5	27.9	62	46.9	92.2
Nijmegen	48.6	58.7	35.9	51.1	58.1
Haarlem	50.5	67.5	65.3	18.7	82.8
Utrecht	52.6	50.1	52.9	54.8	76.2
Den Bosch	56.5		31.7	81.2	69.7
Maastricht	59.2		93.2	25.3	79.5
Den Helder	71.5	50.8	76.9	86.7	79.9
Alkmaar	72.8	74.5	84.6	59.3	63.7
Groningen	77.6	54.7	98.8	79.3	110.2
Zaandam	91.4	103.2	115.5	55.4	67.1

Source: Rutten (1997: 425–48). Note: the index was calculated by dividing the number of vaccinated children by the number of live births by year for each municipality. For an explanation see Rutten (1997: 303).

1860s this dropped to a low 3 out of 10 children. While we lack information on vaccination levels just before and during the outbreak of the 1870s, there are no indications that they were significantly higher than the decade before. However, even if only a third of the population was vaccinated, this could still have a substantial impact at the individual and neighborhood level during an epidemic outbreak. The proportion of vaccinated children in a neighborhood did not only affect the number of people at risk of smallpox infection and death, but also impacted the rate of transmission. Differences across the city may have arisen from an unequal distribution of vaccination across the social spectrum. The case study of Amsterdam is therefore interesting because the availability of neighborhood-level mortality data allows us to indirectly probe some of the possible effects of vaccination on particular parts of the population, such as the Jewish neighborhoods where high vaccination levels are assumed.

Data, Methods and Variables

We use a mixed methods approach combining a qualitative reading of contemporary descriptive sources (e.g., reports by the municipality, local interest groups, and the city's health inspectors) and spatial analysis with OLS regression. The main source of our analysis is the Amsterdam Cause of Death (hereafter, ACD) database compiled by Janssens et al.[1] The dataset contains individual death records between

[1]More information on the research project that created the database can be found on http://doodinamsterdam.nl.

1853 and 1940 with information on the day of death, age, gender, cause of death, residential and/or institutional address, and other sociodemographic characteristics (Bureau voor Statistiek 1854–1940). Our analysis of smallpox focuses only on the period of the smallpox epidemic between 1870 and 1872, and especially on its peak year, 1871. To be able to calculate death rates, population data were taken from the censuses in 1859, 1869, and 1879 (CBS and NIWI-KNAW 1999). Unfortunately, the censuses only provide information on the population by age group or neighborhood, but not in combination. We applied exponential interpolation to obtain mid-year age-specific and total population for the between-census years, including 1871. We calculated the share of each neighborhood in the 1869 census and applied those proportions to the interpolated total population to obtain the population by neighborhood.

To scrutinize the spatial distribution of smallpox across the city, we georeferenced the residential addresses of the deceased as reported in the ACD. We did this by linking the addresses of deaths attributed to smallpox to a geocoded address file composed by the Amsterdam Time Machine.[2] This address file uses geographical coordinates as anchor points (location points) rather than specific geometries of buildings or plots and provides a concordance of historical addresses for those locations in the years 1832, 1853, 1876, 1909, and 1943. We used the addresses from 1853 that were still in use at the time of the smallpox epidemic and used the different Lohman neighborhood atlases composed by the department of Public Works between 1853 and 1870 to locate missing addresses (Dienst der Publiek Werken 1861–1867; 1865–1870). Incomplete addresses were provided a random location point based on the information that was available, such as the neighborhood or street name, using random selection. Smallpox cases that did not have a recorded residential address (4 in 1870, 43 in 1871 and 12 in 1872) were left out of the analysis.

We conduct OLS regression analysis using various neighborhood variables which we constructed from a range of primary sources from a time period as close as possible to the smallpox outbreak. The dependent variable in the regression is smallpox death rate, which is based on the deaths due to smallpox per 1,000 people in 1871 (population census of 1869). The ACD data unfortunately lacks sufficient information on the socioeconomic status of the deceased. Despite the source including a field for occupation, no such information was reported for children, and, adhering to a long tradition of under-recording women's economic contributions, neither was it for women. We use two alternative variables to estimate the impact of wealth on smallpox mortality: (1) the categorization of all 50 neighborhoods into "poor," "rather poor," "rather wealthy," and "wealthy" by the Amsterdam physician Abraham Hartog Israëls (1862) based on his knowledge of the city, and (2) estimates of the rental values of buildings calculated from the taxable yield (*belastbare opbrengst*) obtained from the 1832 land register as discussed in Lesger and van Leeuwen (2012) and linked to the 1,874 addresses. Even though both variables are taken from a period relatively long before the smallpox epidemic, the high correlation (Figure A1 in the Appendix; see supplemental materials) between the mean

[2]For more information on the creation of these address files, see https://www.amsterdamtimemachine.nl/hisgis-clariah/ and https://adamlink.nl/geo/addresses/start/.

rental values and tax declarations from 1897 to 1898 suggests that we can assume that the relative wealth position of neighborhoods was stable in the period of interest.

Additional neighborhood variables include average crude death rate between 1867 and 1870, the standard deviation of rental values, housing density, birth rate in 1874 and two binary variables indicating Jewish neighborhoods and neighborhoods with hospitals. A more detailed description of the regression analysis variables is included in the Appendix (see supplemental materials) and in the section discussing our results.

Results

The spread and distribution of smallpox mortality

It is well known that by the nineteenth century, the death toll of smallpox in large Dutch cities such as Amsterdam had decreased significantly compared to the century before. Preventive measures, but especially cowpox vaccination introduced at the end of the eighteenth century, significantly curtailed the frequency and severity of outbreaks (Rutten 1997: 370–80). Amsterdam followed similar cyclical patterns as other cities like Rotterdam and The Hague. It still experienced surges in smallpox between the 1810s and 1850s, but peak year death counts were cut drastically by 60 to nearly 80 percent compared to the outbreaks at the turn of the century. The epidemic of 1870–72 must have therefore come as a terrible shock, with people witnessing an outbreak that was only comparable in fatalities to ones occurring more than 70 years earlier. In Amsterdam, about 1 in 125 inhabitants succumbed to the disease during these two years (Teixeira de Mattos 1872).

In a demographic sense, the profile of the victims of the 1870–72 epidemic in Amsterdam concurs with what we know about smallpox mortality in nineteenth-century Europe. There was no important sex divide: smallpox deaths in Amsterdam were roughly equally divided among male and female inhabitants and the overall smallpox death rate was equal for both sexes (see Figure 2). One's age group was a factor of more importance. Roughly half of smallpox deaths were divided across the age groups from five years onward. There was a small increase in mortality among the 20 to 49-year-olds, but this pales in comparison to the death toll among young children. As we would expect based on the existing literature (Mielke et al. 1984: 278–81), the greatest blows were served to those ages zero to four (see Figure 2). Among the population, this age group was most likely not vaccinated yet, nor had they had the chance to survive smallpox in the past. They were, in sum, the age group most vulnerable to an outbreak.

Where these victims stood on the socioeconomic ladder is not easy to determine. The cause-of-death registers only provide occupational data for about one in eight smallpox deaths. More than half of these known occupations belonged to the lower classes, but the occupations of women and children below the age of 15 were hardly ever recorded. The large proportion of missing data means that an alternative approach is needed to assess the impact of social differences on smallpox mortality.

To be able to examine social inequalities in more detail, we therefore turn to the social environment that the deceased inhabited. We analyze individual deaths as

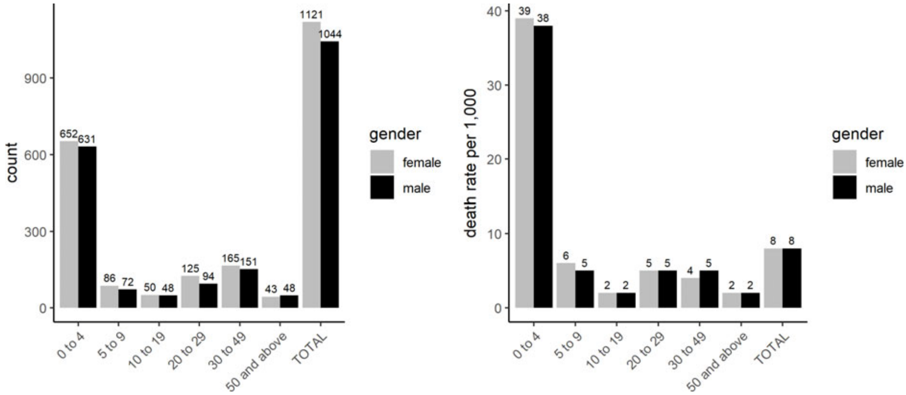

Figure 2. Smallpox death count and rate by age group and gender.

part of one of Amsterdam's 50 administrative neighborhoods, for which we collected additional data using the same geographic divisions. This reliance on administratively defined neighborhoods is not ideal. From a methodological perspective, Xu et al. (2014: 813–14) have warned that true neighborhood effects may be obscured when the measured scale does not match the lived experience. For nineteenth-century Amsterdam, Lesger and van Leeuwen's (2012) work indeed demonstrated that these administrative neighborhoods should not be categorically considered homogenous blocks. Instead, poorer and wealthier residents often lived in each other's vicinities, experiencing "around the corner segregation," with the lower classes residing not only in peripheral parts of the city but also in side streets (Lesger and van Leeuwen 2012: 348).

Fortunately, one's place within Amsterdam's urban landscape was not devoid of meaning regarding one's social standing. Already in the nineteenth century, medical doctors debated how the composition of neighborhoods might affect disease and mortality patterns. Neighborhoods D and E (see Figure 3) were for example considered to be better-off socioeconomically and were also characterized by relatively good health conditions. The opposite was true for the different neighborhoods belonging to the Jordaan (neighborhoods QQ, PP, OO, NN, MM, DD, EE, FF, and GG), which were both infamously poor and unhealthy (Egeling 1861; Teixeira de Mattos 1865). How did the inhabitants of these different neighborhoods fare during the smallpox epidemic of the 1870s? Was smallpox as undiscriminating as contemporary health inspectors believed, or did the spread and distribution of smallpox mortality reveal social inequalities?

Smallpox entered the city of Amsterdam months before our cause-of-death registers recorded its first fatal victim, since not everyone who was afflicted succumbed to it. The yearly report by the supervisory committee of the health service of the city of Amsterdam of 1870 described the sporadic discovery of smallpox cases from April 1870 onward, though it would take until November for the first fatality to be recorded (Verslag 1871: 6–12). All of the initial cases had been reported in the old city center, in the adjacent neighborhoods of K and J (see Figure 3, phase 1). In September a small outbreak was noted in a guest house in neighborhood C, also

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Figure 3. Amsterdam's smallpox epidemic of 1870–72 in five phases.

centrally located, after a family that had recently returned from Paris found out that their 14-year-old daughter was infected, followed by her father and later the guest house host's son. A young child in neighborhood L also contracted smallpox, but survived, as did the others. Smallpox became more widespread in October, brought in by recently returned travelers from Strasburg and Metz, and by those "for whom their occupation necessitated contact with the French" (Verslag 1871: 12).

The spread of smallpox from the old city center to the rest of the city (phase 2) was accompanied by the first fatality of the unfolding epidemic. The first smallpox death of 1870 was attributed to a 4-year-old boy, who died on a ship from Rotterdam on the Schippersgracht in neighborhood U on the right side of the city center. His death was followed by the passing away in the *Buitengasthuis* (XX) of two "polder boys" from Bullewijk, southwest from the city, and, 10 days later, the death of a 14-month-old boy in the Lange Leidsedwarsstraat (JJ). In the month of December, 49 cases were reported, with 11 casualties; more than half of which were now observed outside of the old city center (*Commissie van Toezicht*: 12). By this time, the medical doctors quit reporting on the travels and types of foreign contacts of smallpox sufferers, as it had become clear that new infections now came from within the city itself. During 1871 smallpox swept across the whole city, killing, at its peak, 24 inhabitants a day (phase 3). The disease started to phase out during the early months of 1872 (phase 4), though it took until the end of the year for the epidemic to stop making victims in all neighborhoods (phase 5).

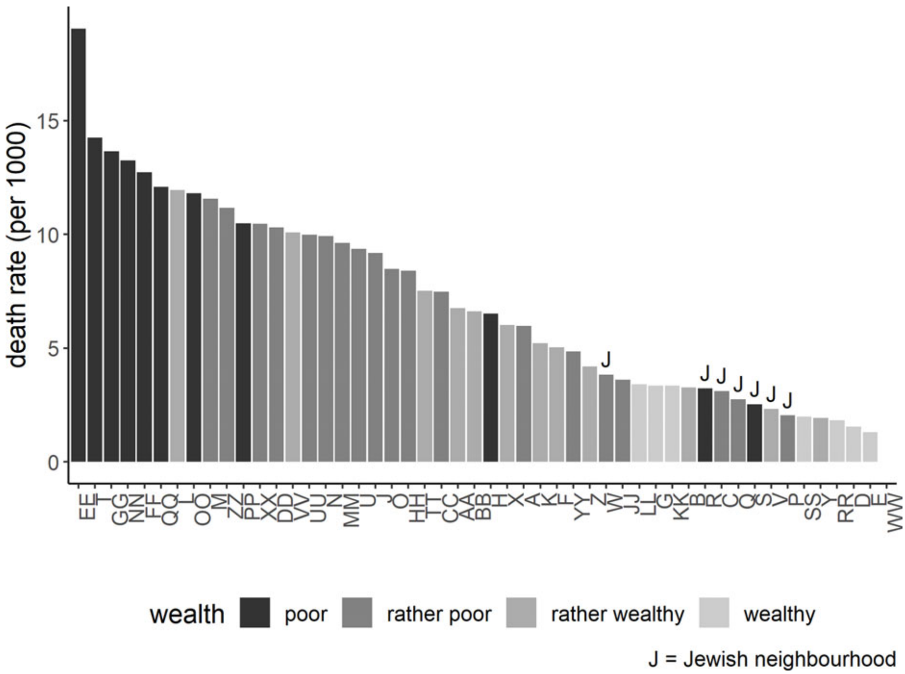

Figure 4. Smallpox death rates in Amsterdam's neighborhoods.

A clear picture of spatial differentiation emerges from an examination of the neighborhoods most affected by the epidemic. Figure 4 shows the smallpox death rate per 1,000 inhabitants of Amsterdam's fifty neighborhoods in the worst year of the epidemic, 1871. The use of death rates rather than the death counts allows us to correct for the varying population sizes of the neighborhoods. This also means that, if chances to succumb to smallpox were equal across Amsterdam's urban landscape, the height of the bars should not substantially differ between one neighborhood and another. This was not the case. On the contrary: Figure 4 reveals vast variation in smallpox mortality. The neighborhoods with the highest smallpox mortality are double or triple the mortality rate of the neighborhoods with the lowest. Moreover, the shades of gray which follow Israëls' wealth categorization reveals something similar to a social gradient (see Figure A2). This gradient is not perfect, but is nevertheless quite remarkable for a rather rough geographical demarcation such as the administrative neighborhoods. It reveals that the aforementioned wealthy neighborhoods D and E did exceptionally well during the pinnacle of the smallpox epidemic. This could, in part, be coincidental due to the capricious nature of contagious diseases, though it is striking that many of the neighborhoods that did relatively well during the epidemic were by and large also those that were regarded as being among Amsterdam's wealthiest.

A disruption to the spatial pattern is caused by the Jewish neighborhoods, marked in Figure 4 with a J. The medical doctor Teixeira de Mattos, an authoritative member of the Amsterdam health committee and prolific public health publicist, already noted in the 1860s that neighborhoods with substantial proportions of Jewish inhabitants were known for their favorable mortality rates, even when the small and densely packed houses amid narrow, dark, and shabby streets they inhabited would intuitively suggest otherwise (Teixeira de Mattos 1865: 202–23). In fact, based on the deaths that had occurred between 1856 and 1862, the impoverished Jewish neighborhoods R and S fared about as well as the most well-off neighborhoods on the ring of canals – for reasons that were speculated to lie in the sphere of anything between the favorable local air, soil, and water conditions, to breastfeeding practices, nutrition, and the lack of alcohol abuse or prostitution by the Jewish (Teixeira de Mattos 1865: 209–10). For smallpox specifically, high vaccination uptake among Jewish communities has been assumed. Scholars have noted the striking number of Jewish doctors active in the field of social medicine and public health care, their steady involvement in the Hygienist public health movement, and public display of support for vaccination (Houwaart 1991; Ruderman 2002; van Poppel et al. 2002: 278; Blom and Cahen 2017: 296). It seems plausible that medical knowledge about the benefits of vaccination spilled over to the Jewish communities and bolstered vaccination uptake. Nearly all Jewish inhabitants were vaccinated in their youth, and many had themselves and their children re-vaccinated (Rutten 1997: 153). In the city of Nijkerk (in the province of Gelderland), only 4.3 percent of the Jewish population contracted smallpox, compared to 9.6 percent of their Christian counterparts. In Amsterdam, too, the Jewish neighborhoods did remarkably well, regardless of their wealth status.

Neighborhoods with very bad death rates were EE, T, GG, NN, FF, and QQ. All but one of these neighborhoods belonged to a region on the west side of the city center called the Jordaan, and the remaining neighborhood T consisted of the Eastern Islands of Kattenburg, Wittenburg and Oostenburg. These specific neighborhoods featured prominently in the reports that became more and more common with the advancement of medical science, the emergence of the hygienist movement, and increasingly poor living conditions due to the population growth during the second half of the nineteenth century. Ranking among the unhealthiest of districts, the Jordaan often took center stage. The conditions were assumed to have improved somewhat since the 1850s after the filling of some muddy canals, the breaking down of several slum houses, and their replacement with "efficient, healthy houses for the working class" (Teixeira de Mattos 1865: 230–32). However, in spite of these efforts, this area was still characterized as the poorest of the city (Israëls 1862: 292).

What is certainly believed to have been detrimental to the health of the neighborhoods in the Jordaan were poor housing conditions, such as the high numbers of cellar dwellings, slum houses built in the alleyways between buildings (*gangen*), and conjoined units of small one-room dwellings (*woonkazernes*). Inhabited cellars, which were often storage rooms-turned dwellings, were widespread – reports record at least 800 of them in 1873, with 3,372 inhabitants – even though two-thirds of them were deemed uninhabitable by Amsterdam's health committee (Allebé 1874: 170). Because the land on which the Jordaan was built had not been raised, both the inhabitants of the alleyway slums and especially the cellar dwellings suffered from excess water due to rising groundwater as well as high water levels in the canals after rainfall. Cellars regularly flooded and remained so for days, with all that this entails for the health of its many inhabitants. Furthermore, in 1860 neighborhood QQ counted no less than 93 inhabited alleyways, a situation that largely remained unaltered by the end of the century according to an account of the condition of laboring class dwellings in Amsterdam (van der Pek and Kruseman 1893: 19). Contemporary medical doctors noted a significantly higher level of mortality: in those alleyway slums 4.69 percent of the population died in a given year, compared to 2.88 percent of the population living on "regular" streets or canals within the same neighborhood (Egeling 1863: 588).

Contrary to the Jordaan, the bad health status of the Eastern Islands of Amsterdam was considered somewhat of a peculiarity to contemporaries. For example, neighborhood T was not plagued by stagnant water in the canals, nor was there a lack of fresh air (Israëls 1862: 293–94). It also had no slum alleys and alleyways the way that the Jordaan did. Nevertheless, the islands Kattenburg, Wittenburg, and Oostenburg were considered very unhealthy and were hit disproportionally hard during various earlier epidemics, such as cholera in 1866 and smallpox in 1858 (Egeling 1861: 142; Allebé 1874: 173). Contemporary medical reports discussed this neighborhood's population density and the prevalence of cellar dwellings. Indeed, according to the 1869 census, neighborhood T ranked fifth of the highest house density in the city. This region also counted the utmost number of these cellar dwellings in the entire city: no less than 368 with 1628 inhabitants according to a survey by the Amsterdam health committee in 1873 (Allebé 1874: 166). Described by the committee as "wretched caverns," nearly half of these cellar dwellings were deemed completely uninhabitable. With an average size of fifteen square meters shared by an entire household, cellar dwellings generally lacked any form of adequate ventilation and sanitary facilities. In the smallpox year of 1871 the average mortality in these cellars dwellings was one per 28.3 inhabitants, while the average of the city as a whole between 1869 and 1872 was one per 37 (Allebé 1874: 173).

While the examples above do not provide conclusive evidence, they convey why contemporaries presumed cramped, densely populated housing to have played an important role in the spread and high share of mortality in these neighborhoods due to contagious diseases like smallpox. In the next section, we therefore conduct statistical analyses of neighborhood differences in smallpox mortality rates.

Regression analysis

Table 2 shows the results of the regression analysis performed on variables measured at the neighborhood level, in which the neighborhood smallpox death rate is the dependent variable in each model. Model 1 investigates if the smallpox mortality pattern is similar to the general mortality pattern. The significant positive coefficient of the average crude death rate suggests that smallpox mortality was higher in neighborhoods where general mortality was higher. Since the spatial analysis conducted in the previous section has revealed the peculiar position of Jewish neighborhoods, we introduce a binary variable to capture their importance. While the coefficient of the average crude death rate remains essentially the same in Model 2, Jewish neighborhoods turn out to be associated with lower smallpox mortality compared to their non-Jewish counterparts. This result is in line with the descriptive findings and the discussion of existing literature above.

Table 2. Regression analysis

Neighborhood variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
average CDR	0.628*** (0.187)	0.580*** (0.159)			0.138 (0.098)	0.164* (0.097)
wealth (ref. cat.: poor)						
rather poor			−2.550** (1.093)		−2.261* (1.145)	
rather wealthy			−3.183** (1.396)		−2.993** (1.427)	
wealthy			−6.181*** (1.503)		−5.543*** (1.622)	
mean rental value (log)				−4.127* (2.275)		−3.828* (2.219)
std. dev. of rental value				0.002 (0.008)		0.004 (0.008)
house density			0.584*** (0.199)	0.645*** (0.212)	0.504** (0.194)	0.558*** (0.174)
Jewish neighborhood		−4.009** (1.566)	−8.387*** (1.406)	−8.375*** (1.714)	−7.715*** (1.416)	−7.538*** (1.595)
birth rate			0.093** (0.039)	0.052 (0.063)	0.088** (0.040)	0.052 (0.065)
hospital neighborhood			−0.069 (1.032)	−0.249 (0.917)	−0.169 (1.050)	−0.493 (0.944)
constant	−9.854** (4.782)	−8.010* (4.275)	1.778 (3.193)	22.168* (12.846)	−1.244 (4.056)	16.709 (12.939)
R-squared	0.310	0.415	0.692	0.687	0.701	0.700
Adj. R-squared	0.296	0.390	0.641	0.640	0.642	0.647
N	50	50	50	47	50	47

Note: robust standard errors are in parentheses, ***p-value $<$ 0.01, **p-value $<$ .05, *p-value $<$ .1.

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Model 3 and 4 are designed to investigate how variables related to the social environment explain smallpox death rates. An important difference between the two models is that they apply a different proxy for wealth. Model 3 relies on the wealth distinction provided by Israëls (1862), while Model 4 makes use of the estimated rental values and their standard deviation. Since the latter variable captures how much on average individual rental values deviate from the mean by neighborhood, we consider it as a proxy for within-neighborhood wealth inequality. The lower the standard deviation, the smaller the inequality. Unfortunately, rental values are not available for three neighborhoods (WW, XX, and ZZ) which were categorized as "rather poor" by Israëls. Regardless of the wealth proxy we used, poorer neighborhoods seem to have suffered more from smallpox deaths. The standard deviation of the rental values does not seem to explain smallpox mortality differences. Another variable that we introduced is the presence of hospitals because in London the district that was most severely affected by smallpox was the one containing the smallpox hospital (Hardy 1993: 137–40). While contemporary doctors attributed the increased incidence in these districts to the visitation of the sick wards, the lack of disinfected ambulances, drivers stopping for refreshments, and tradesmen being admitted onto the grounds, it can be argued that these districts also simply contained a large poor population. For Amsterdam, the wealth indicators are indeed more relevant to explain smallpox mortality differences, since the binary variable controlling for the presence of hospitals is not significant. Smallpox death rate is higher in areas with higher housing density, which is something we will elaborate on in the discussion. The coefficient of the Jewish neighborhood variable remains negative and significant at the 1 percent level.

To gauge the potential susceptible population, we also included a variable consisting of the birth rate in the different neighborhoods. The estimated coefficient of birth rate is not robust across model specifications: while Model 3 suggests that smallpox death rate is higher in neighborhoods where more children are born per 1,000 people, it does not turn out to be a significant determinant in Model 4. One explanation for this difference might be that the significance of the coefficient is sensitive to the exclusion of the three neighborhoods for which rental value information is not available. To test this, we redid Model 3 on a limited sample of the 47 neighborhoods for which we do have rental value estimates (not reported), but the results essentially remained the same. The other possible explanation is based on the fact that the wealth classes by Israëls' are categorical variables, while the mean rental value is continuous. Categorical variables do not distinguish between observations, in this case neighborhoods, in the same group, while the variable measured on a continuous scale assigns a different value to each neighborhood. Thus, if wealth and birth rate are closely related, the continuous wealth proxy is expected to capture this better and the birth rate is more likely to turn insignificant in model 4.

In the last models, 5 and 6, independent variables on mortality and socioeconomic environment are combined. The size and significance of the estimated coefficients of the socioeconomic variables in Model 3 and 4 change slightly, but the results essentially remain the same. The most important finding is that the average crude death rate turns insignificant in Model 5 and becomes lower and significant at the 10 percent level only in Model 6 (p-value = 0.099). This change is probably because the crude death rate is largely explained by the same socioeconomic factors as the smallpox death rate. When both groups of variables are included in the model, the significance of the average crude death rate reduces to a large extent. This also means that adding it on top of the socioeconomic environment variables does not contribute substantially to the explanatory power of the models.

Discussion

The results of the regression analysis demonstrate that wealth, house density, and having a substantial Jewish population are important in explaining neighborhood variation in the impact of smallpox within the city. But how should we understand these findings? And what can we say about aspects that we are unable to measure? During the second half of the nineteenth-century medical doctors and other concerned citizens ruminated on possible causes of mortality differences across the population of Amsterdam. In the reports that they produced, they pointed to various sociodemographic aspects such as living conditions, access to clean water, house density, and migration rate.

Important insight into the living conditions of large segments of the Amsterdam population can be given by an important report from the 1890s surveying the plight of the working-class poor – conditions that were unlikely to have been any better during the smallpox epidemic two decades earlier (van der Pek and Kruseman 1893). Structurally, it noted that most of the dwellings only had one window, which made it difficult to properly ventilate a room and to let in light. In the context of smallpox this is a factor of importance, since the virus is believed to die out relatively quickly when exposed to ultraviolet light (Rutten 1997: 141). The general lack of access to clean water by large parts of the working class was also disadvantageous for handling smallpox contagion. With surface water that medical doctors deemed unsuitable for cooking and washing, and remaining largely unconnected to the expanding grid of water pipes even by the end of the century, most inhabitants of the Jordaan had to purchase water from so-called water and fire establishments (van der Pek and Kruseman 1893: 37–8). Aside from the accompanying costs, these establishments could easily be a 5-to-10-minute walking distance away. These impediments did not benefit the regular washing of houses and clothing, while this was important in the prevention of smallpox infection through dander.

House density had a significant, measurable effect on smallpox mortality across Amsterdam's neighborhoods. Faced with an outbreak, the elite could escape the city as a precaution, but importantly also had better opportunities to isolate an infected family member in a separate room to prevent further spread of smallpox among the rest of the family (Rutten 1997: 141). With an average living space of less than 10 square meters, shared by between five and nine household members, most inhabitants of the poorer neighborhoods clearly had no such luxury (van der Pek and Kruseman 1893: 26). Our regression analysis also demonstrates that birth rates are significant variables in a neighborhood's smallpox mortality. Neighborhoods with lower numbers of births per 1,000 inhabitants also had lower smallpox death rates. On average, these were the wealthier neighborhoods, whereas the Jordaan and the Eastern Islands were characterized by higher birth rates. As we have seen, young children below the age of four carried the largest burden of death in smallpox in

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Amsterdam during the epidemic of the 1870s. Children within this age group were often not vaccinated yet, nor had they already gained immunity by surviving the disease. Neighborhoods with higher birth rates thus made for a larger population susceptible to smallpox. We have not been able to locate any data on vaccination degrees by neighborhood, but it is generally assumed that vaccination campaigns were less successful at the bottom of the societal ladder (Rutten 1997: 131).

A neighborhood's migrant rate may have also been a factor that rendered some neighborhoods more vulnerable than others. Smallpox outbreaks are believed to have been less common and less severe in rural areas and smaller cities in the Netherlands (Rutten 1997: 403). This meant that people could more easily reach adulthood without ever having contracted smallpox, or without having been vaccinated. When they moved to a large city like Amsterdam, they were especially at risk. This is also suggested by Figure 2b, which provides age-specific smallpox death rates, and demonstrates that death rates were elevated in the age groups where adult migrants were concentrated (between 20 and 49) compared to the adjacent age groups. Unfortunately, we currently lack the necessary neighborhood level data that could provide more direct evidence, but we assume that the increasing numbers of predominantly lower to lower-middle class migrants to the city (Suurenbroek 2001: 26–30) resulted in higher migrant rates in the poorer neighborhoods. It seems plausible that this influx contributed to a larger susceptible population during the epidemic of the early 1870s.

Finally, a brief examination of better-off areas also suggests that smallpox mortality seems to follow the logic of the city's established socioeconomic patterns. The overall lack of cases among the affluent neighborhoods of the northern canal belt, particularly on the addresses facing the canals inhabited by the well-to-do, is nothing less than striking. House densities in these neighborhoods were very low. Neighborhood RR, for example, belonged to the top 8 percent of lowest number of people per inhabited house, while also having one of the lowest birth rates of the entire city. The area south of the Vijzelstraat between the Herengracht and the Lijnbaansgracht (distributed over the neighborhoods X, BB, and AA) belonged to the southern canal belt and was categorised by Israëls as "rather wealthy." Density per house was higher than in wealthiest neighborhoods, but lower than in about 60 percent of the rest of the city. Birth rates were slightly on the lower end of the city average, as were the smallpox death rates. Interestingly, when we analyze individual-level deaths within this area, we can see a clear differentiation between the building blocks of the consecutive canals surrounding the city center. This mortality concentration appears consistent with the accompanying house densities and rent values as proxies for wealth of these housing blocks. Smallpox deaths were mainly concentrated in the southern ring – the area with the highest population density and the lowest rent values – while the northern rings incrementally fared better. Underneath the level of administratively defined neighborhoods, we can thus find further evidence for a distribution of smallpox death along socioeconomic lines.

In sum, our analysis of the spread and distribution of smallpox mortality across Amsterdam's population suggests that not all faced equal risks. This raises the question whether smallpox created this particular mortality disparity, or aggravated existing health inequalities. Figure 5 allows us to shed light on this by comparing the smallpox death rate to the average crude death rate calculated from all-cause

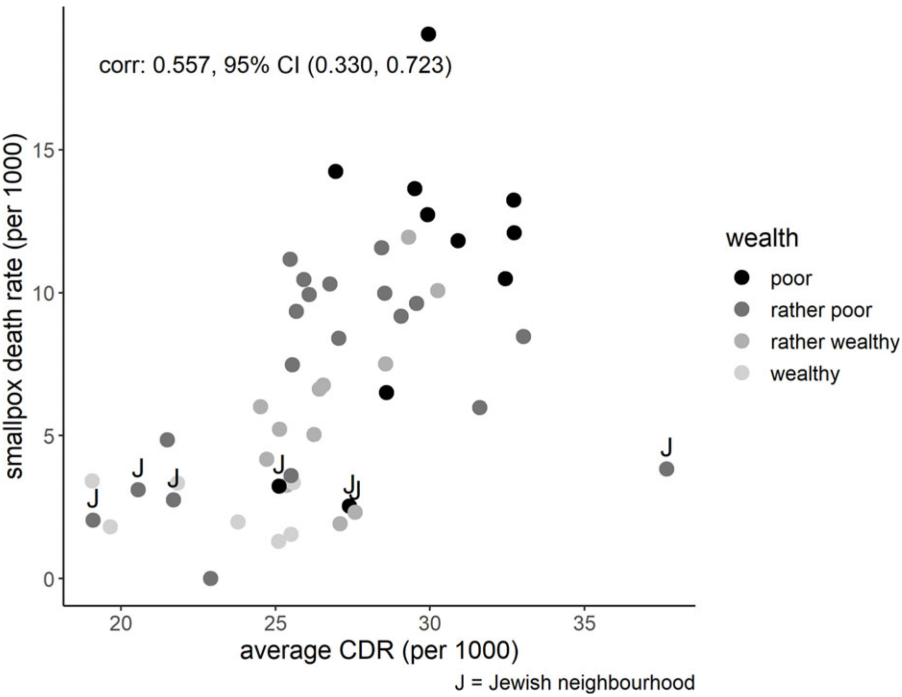

Figure 5. Smallpox death rates compared to average crude death rates by neighborhood.

mortality during the four years preceding the peak of the smallpox epidemic. With each grey-scaled dot representing a neighborhood following Israëls' wealth classification, this figure demonstrates that in general the areas hit harder by the smallpox epidemic were also the areas that had higher overall mortality rates the years before the epidemic. On average, the wealthier neighborhoods did better. The Jewish neighborhoods also experienced low smallpox mortality, in spite of their average wealth or crude death rate. We assume that this deviation from the logic of wealth categorizations was related to high vaccination uptake among the Jewish population.

With the notable exception of these Jewish neighborhoods, we presume that in most cases the determinants for a higher crude death rate and higher smallpox mortality might be similar. Smallpox mortality thus mirrored existing socioeconomic differences that existed within the city, not only between rich and poor, but also on smaller scales of building blocks and streets. Poor neighbourhoods largely lacked the conditions necessary for healthy living and are furthermore assumed to have suffered from lower smallpox vaccination rates. It therefore comes to little surprise that many of these poorer neighborhoods were not only hit hard by the epidemic of 1870–72, but also saw the disease linger for the longest time. While most of the city had cleared up, no less than 40 out of the 50 last people succumbing to smallpox in 1872 from June onward resided in the Jordaan neighborhoods. In a period without universal vaccination uptake, the spatial distribution of smallpox deaths lays bare some of the deep-seated social and health inequalities across the city.

Conclusion

The main aim of our study was to examine the role of neighborhood-level social inequalities in the impact of the smallpox epidemic in Amsterdam between 1870 and 1872. Our analyses confirm that the burden of smallpox at this time mostly fell on young children below the age of 4 years and reveal that the impact differed significantly by neighborhood. The overt social differentiation in smallpox mortality in nineteenth-century Amsterdam contrasts commonplace assumptions about the indiscriminate nature of smallpox (Rotberg and Rabb 1985; Snowden 2019). Moreover, we argue that the spatial patterning of smallpox mortality can largely be understood through the same sociodemographic neighborhood characteristics that also explain existing general mortality disparities. This finding is congruous with the observations of Rafferty et al. (2018) and Rutten (1997), who noted important geographical variation in smallpox intensity at national levels, brought forth by a series of sociodemographic factors impeding disease control. Our study reveals that on a local level, too, the smallpox epidemic mirrored and exacerbated existing social inequalities.

Using a mixed methods approach to address the question which neighborhoods were most affected by the epidemic, we discern a clear spatial differentiation. We consider these differences across the urban landscape an indication of a rough social gradient: many of the neighborhoods that did relatively well during the smallpox epidemic were wealthier, while those doing worse were poorer. Our regression analysis demonstrates that neighborhood wealth and housing density were important factors in explaining variation in the impact of smallpox within the largest parts of the city. We infer from this the importance of particular socioeconomic realities in determining one's fate amid an epidemic outbreak: after all, the highest smallpox rates were found in the Jordaan and the Eastern Islands, parts of the city that were well known for the poor housing conditions in their abundant slum and cellar dwellings. Qualitative sources point out that various other sociodemographic aspects such as living conditions and migration rate may further explain observed differences in smallpox rates between neighborhoods.

However, our sources do not allow us to directly distinguish the effects of vaccination from these neighborhood-level factors. Since it is commonly assumed that vaccination uptake was socially differentiated (Rutten 1997: 131), the patterns we observed could also have been driven by social gradients in vaccination. In history, negative associations between socioeconomic status and mortality (i.e., lower mortality among the wealthier) were not a constant, but varied over time and by disease (Clouston et al. 2016). The observed wealth advantages during the smallpox epidemic of 1870–72 therefore touch on a larger debate on how the advent of smallpox vaccination may have led to the emergence, exacerbation, or reduction of socioeconomic gradients in mortality throughout various stages in time.

The impact of vaccination is highlighted by the Jewish neighborhoods. These neighborhoods constitute an important exception to the general relationship that we observed between socioeconomic environment and smallpox mortality by doing exceptionally well during the smallpox epidemic in spite of their infamous poverty and crowdedness. Even though we lack data on neighborhood vaccination rates, the relative success of these Jewish neighborhoods (often lauded for their high vaccination uptake) during the epidemic is suggestive of its importance. As such, the Amsterdam case study highlights how socially and economically deprived parts of the population were more vulnerable to the burden of epidemics, but that these disadvantages may be offset by health interventions such as vaccination in the case of smallpox. In spite of the availability of a suitable medical intervention, the 1870s smallpox epidemic in Amsterdam proved not to be socially neutral. Lacking universal vaccine uptake, the epidemic instead continued to shape and exacerbate deep-rooted social and health inequalities within the city.

Our results demonstrate that it is possible to study social inequalities in health by examining the impact of an epidemic across a city such as Amsterdam. The neighborhood approach allows us to scrutinize intra-urban social inequalities otherwise levelled out in city-wide or regional-level analyses. Nevertheless, our study also has some limitations that further research should try to overcome. The most important limitation is that currently the neighborhood is the lowest level at which we can analyze smallpox mortality due to the lack of population data on house and street level. So although we acknowledge that administrative neighborhoods are far from homogeneous, we cannot take their heterogeneity into account. Additionally, the available neighborhood-level information that can be included in statistical analyses is limited. It is therefore impossible to test the effect of other determinants on mortality, although we have tried to overcome this by explicitly examining more qualitative sources that shed light on the general living conditions and environment. Finding a way to include data on intra-urban vaccination levels would significantly enhance our understanding of the observed relationship between neighborhood-level determinants and smallpox mortality. Finally, in the same way that the specific social, economic and demographic structure of Amsterdam during the early 1870s may not necessarily be representative for the experiences in other urban settings, different sociodemographic factors may be of importance for epidemics other than smallpox. Studies taking a similar approach to different cities and/or different diseases may therefore help to uncover in what ways our findings are specific or universal in demonstrating persistent social inequalities in infectious diseases (Riswick et al. 2022).

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ssh.2022.31

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