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Using cadastral maps in historical demographic research: Some examples from the Netherlands

Peter Ekamper *

Netherlands Interdisciplinary Demographic Institute (NIDI-KNAW), P.O. Box 11650, 2502 AR, The Hague, The Netherlands

Abstract

Historical cadastral maps can be a very useful additional source in historical demographic research. As an increasing range of geospatial data and tools have become available to researchers, it becomes easier to combine, link and analyse historical micro level demographic data within a small-scale spatial context. This study shows some examples of linked cadastral map data, population census data, and population register data of the Dutch city of Leeuwarden halfway the nineteenth century. The spatial methods and techniques used vary from relatively easy visualisation in maps and basic spatial statistics to more advanced spatial modelling.

Keywords: Cadastral maps; Population census; Geovisualisation; Spatial analysis; Spatial regression

1. Introduction

In the last few decades the role of geographical information and computing technologies (geo-ICT) in scientific research increased tremendously. An increasing range of so-called geospatial data and tools, like geographical information systems (GIS) and geospatial analysis methods and techniques, have become available to a widening body of researchers and academic disciplines (Van Manen, Scholten, & Van de Velde, 2009). Also in historical and (historical) demographic research the role of geo-ICT is becoming more and more important (Boonstra, 2009; Gregory & Ell, 2007; Knowles, 2008b; Stillwell, 2009). At the same time the availability of historical spatial data like historical maps and historical census data in digitised forms is increasing. There has been major progress for instance in developing historical GIS databases containing both (changing) administrative boundaries and census (and similar) data from the early nineteenth century—when a lot of countries started statistical data collection—to the present (Gregory & Healy, 2007). The Great Britain Historical GIS (Gregory, Bennett, Gilham, & Southall, 2002) and the USA National Historical GIS (McMaster & Noble, 2005) are interesting examples of national historical GIS projects. Traditionally, this type of historical GIS projects focus on administrative spatial units like counties, municipalities, wards, districts, or neighbourhoods combined with demographic and other socio-economic data (Knowles, 2008a). However, the scientific interest of many demographers has shifted in recent years from studying "demographic regimes" and large-scale processes to analysing longitudinal data at the micro level in the form of individual "life courses" (Kok, 2007). Some

* Tel.: +31 70 3565233.
E-mail address: ekamper@nidi.nl.

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historical longitudinal micro datasets are available to researchers already, like the Historical Sample of the Netherlands (Mandemakers, 2002) and the Swedish Demographic Database (Edvinsson, 2000) as well as historical population census and register data, like the Dutch national genealogical database (Genlias, 2009). Data sources like these provide various characteristics and events at the individual and household micro level. The corresponding spatial context is that of the place of living of the individual or household (or other places of importance to life course events) at the micro level, viz. dwellings and other buildings. From a spatial perspective, studying data at the micro level implies not only reconstructing individual life course events but also reconstructing the corresponding micro geographical locations. To be able to identify and visualise geographical locations one basically needs to connect dwelling addresses to locations on maps as detailed as possible. Usually the most accurate and smallest scaled maps available are cartographic records of property ownership, viz. cadastral maps. However, examples of the use of cadastral maps in geospatial analyses usually focus on the data directly included in the cadastral registers, that is data on ownership and owners, but not the occupants, see for instance Gruber (2000), Hanus (2008), Lelo and Travaglini (2005), and Toftgaard Jensen and Keyes (2003).

Combining (cadastral) cartographic data with other data sources can be of particular use to historical demographic research. The potential additional value of using demographic and other socio-economic data from other sources combined with small-scaled cadastral spatial locations instead of aggregated (administrative) spatial units is illustrated in Fig. 1 by an example of the city of *Leeuwarden* in the north of the Netherlands. Fig. 1a visualises the population density in the inner city (within the moat) of Leeuwarden by census district according to the population census of 1839. According to the map population density is highest in the centre of the city and decreases with distance from the centre. The western part of the city is less densely populated than the eastern part. However, visualising the same data with the much more detailed cadastral map of 1832 produces a rather different picture. Fig. 1b shows the population density by dwelling. Population density appears to be highest at the borders near the fortifications. In the eastern part of the city the soldiers barracks in the northeast and the prison in the southeast stand out. The second map much better reflects the living conditions in the city, where the upper and middle class mainly lived in the larger housing in the centre and the poor in the small housing in bad repair on the outskirts.

2. Cadastral maps

Cadastral surveying, registration and mapping has a long tradition in several countries, like the Netherlands and Sweden, with very early mapped cadastral surveys from the beginning of the seventeenth century (Kain & Baigent, 1992). However only during the nineteenth century most countries started to produce really precise and small-scaled cadastral maps (Kain & Baigent, 1992). The modern Dutch cadastre originates from the period of French annexation by Napoleon from 1810 to 1813. The French rulers considered it important to revise the collection of land tax by establishing a new and accurate mapped cadastre in line with the official instructions of the French cadastre known as the *Recueil Méthodique* (Ministre des Finances, 1811). After the retreat of the French the work on the cadastre stopped, but was taken up again in the southern Netherlands in 1814 and the northern Netherlands in 1816 (Kain & Baigent, 1992). The maps, called *minuutplans*, were drawn at a scale of 1:1250 in areas with more than five parcels per hectare, 1:5000 in areas with parcels on average larger than 5 ha, and 1:2500 in all other areas, resulting in a production of almost eighteen thousand maps in a period of almost twenty years (Kain & Baigent, 1992). Parcels were numbered on the map corresponding with the number scheme of the cadastral ledgers which contain name, place of residence, and occupation of the land owners, as well as type of land use, area, and taxable value classification. The surveying was completed in 1831 and the Dutch Cadastre became operative formally in 1832.

3. Geo-referencing and vectorisation of historical maps

In the period 2001–2003 the almost eighteen thousand maps and the accompanying 150,000 pages of the cadastral ledgers of the Dutch Cadastre of 1832 were digitised in the form of digital scans (or raster images) and made public through a website, a joint effort of the Dutch national and regional archives (WatWasWaar, 2009). However, these types of scanned raster maps are as such not usable in GIS based methods and techniques. To be able to use raster maps in geographical information systems they need at least to be geo-referenced. *Geo-referencing* is the process of assigning spatial coordinates (like latitude and longitude or national systems coordinates) of known locations to the corresponding points on the raster image of the map. Geo-referencing is a fundamental GIS operation: it produces real-world coordinates, that can be used to calculate distances and areas in real-world units, and the

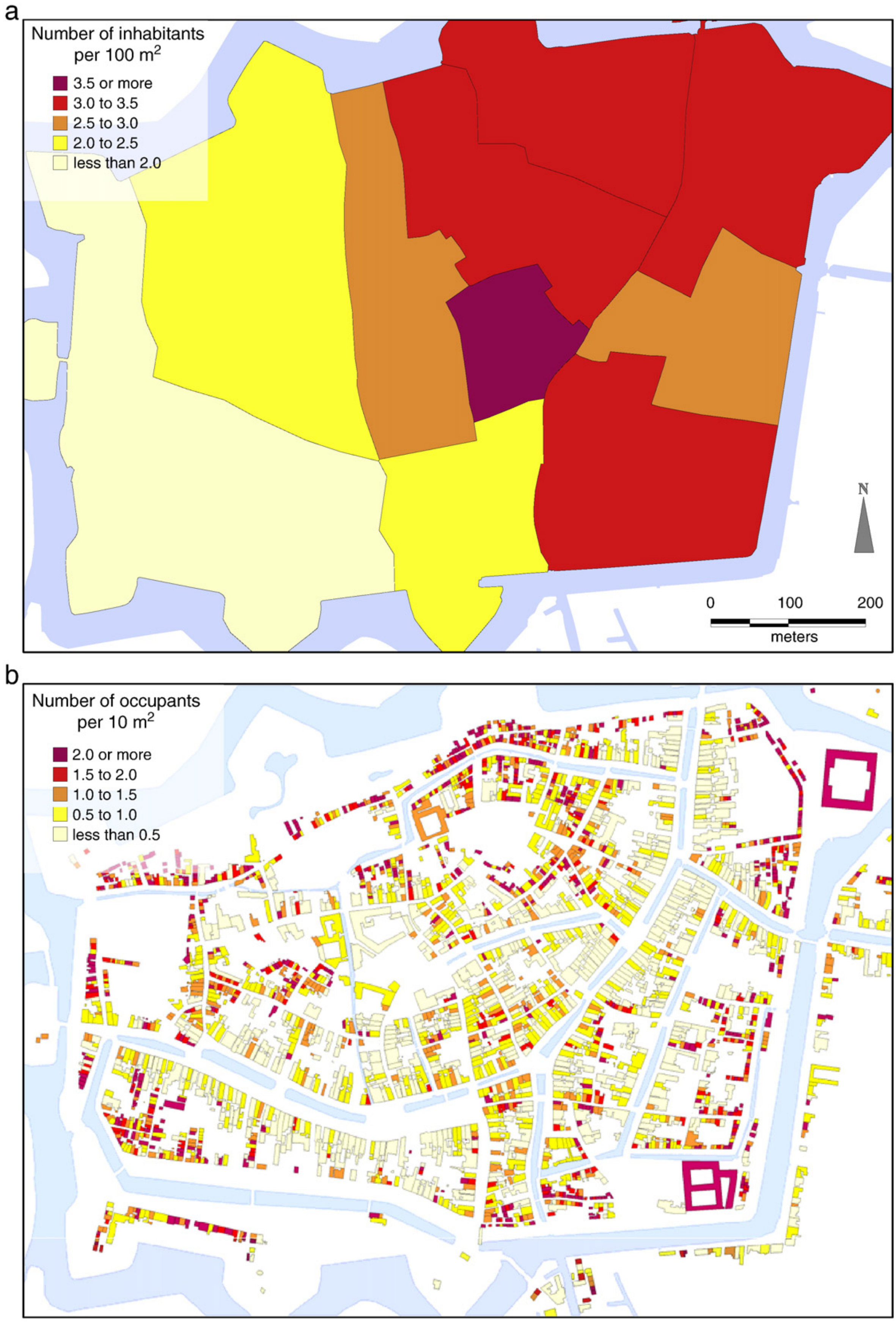

Fig. 1. Population density in the Dutch city of Leeuwarden by census district (a) and dwelling (b) according to the population census 1839.

geo-referenced map can be combined or integrated with other geo-referenced maps (Gregory & Ell, 2007). A step further is to not only geo-reference a map, but to also vectorise a map. *Vectorisation* is the process of converting symbols and lines on a raster map to vector objects like points, lines and polygons. However, precise vectorisation of a map is a very time-consuming process. A vector representation of a map is more abstract and has more functionality than a raster map, but might lose some of the contextual information (Gregory & Ell, 2007). On the other hand with vector maps different types of information, like roads, rivers, lots, buildings, and administrative boundaries can be stored in separate map layers. In illustration Fig. 2 presents different examples of the same fragment of the cadastral map of the Dutch town of Woerden. Fig. 2a is the scan of the original cadastral map of the Dutch Cadastre of 1832. In Fig. 2b the lines of the original map are converted into vectorised lines and objects. Fig. 2c shows the vectorised map, where the different types of objects are stored in separate layers for buildings, lots and streets. The buildings are visually distinguished in church buildings and other buildings. As a reference Fig. 2d shows the situation according to the 2004 cadastral map of the current Dutch Land Registry Office (*Kadaster*).

For some parts of the Dutch cadastre of 1832 the cadastral maps have been geo-referenced and vectorised already; the most advanced example being the whole of the Dutch province of Friesland (HISGIS Fryslân, 2009) covering approximately 11% of the area included in the Dutch Cadastre. A few other larger projects covering other provinces will be ready soon. However, the main part of the country is not covered yet at all including major cities like Amsterdam and The Hague.

4. Dutch cadastral maps and population data

The Dutch cadastral maps of 1832 are accompanied by cadastral ledgers (*oorspronkelijke aanwijzende tafels*). These cadastral ledgers include data on ownership organised by cadastral numbers. Unless the owner is living at his or her own premises the cadastral ledgers do not provide information on the occupants. However, other data sources like population censuses, population registers, and health registers do provide this information. To put these types of data on persons and households into a geographical perspective at the level of cadastral maps one needs to link the person or household data to the cadastral units. However, house addresses and house numbering from sources like population censuses and registers usually are different from the cadastral numbering and are not linked. Both house numbering and cadastral numbering might also have changed over time. Therefore, linking other data sources to the cadastral maps can be a difficult and time-consuming task.

The most important sources for population data are population censuses and registers. Only just in the nineteenth century in many European countries among which the Netherlands, population censuses became an important tool of statistical observation. The first general population census of the Netherlands took place at the end of the year 1829 after a royal resolution of September 3, 1829. Since then, population censuses ought to be carried out every ten years. Accordingly, the second general population census of the Netherlands took place at the end of 1839. The decennial general population censuses in the Netherlands stopped after 1971. Civil registration of births, deaths and marriages in the Netherlands originates from the period of French annexation and started in 1811. Continuous population registration started in 1850 by law.

5. Spatial analysis methods and techniques

Within a historical demographic research context, spatial analysis methods and techniques can roughly be distinguished in three broad groups ranging from relatively easy to complex approaches, viz. (geo)visualisation, exploratory spatial data analysis (ESDA), and spatial modelling and regression. Geovisualisation basically focuses on visualising spatial data in maps. Several types of thematic maps can be used to present spatial patterns, like choropleth ('shaded' or 'pattern') maps, (proportional) symbol maps, flow maps, and cartograms. Exploratory spatial data analysis aims at finding or comparing spatial patterns by using spatial statistics and spatial indicators, like spatial (weighted) means, standard mean distances, standard deviational ellipses, and spatial autocorrelation statistics such as Geary's G and Moran's I. Spatial modelling and regression techniques aim at explaining spatial patterns by using spatial (regression) models. The use of advanced spatial analysis methods and techniques are extensively dealt with in for instance Anselin (1988), Anselin, Syabri, and Kho (2006), Chi and Zhu (2008), Eck, Chainey, Cameron, Leitner, and Wilson (2005), Gregory (2005), and Gregory and Ell (2007). Gregory and Ell (2007) particularly focus on the use of spatial analysis methods and techniques in historical research. Eck et al. (2005) present a very useful overview of examples of various spatial analysis methods and techniques albeit a different subject of research. In the following sections

Fig. 2. Different presentations of a fragment of the cadastral map of the Dutch town of Woerden in 1832 and 2004.

some examples of the Dutch city of Leeuwarden will be presented using several methods and techniques. Some of the examples are based on a study of Ekamper and Mol (2008) using the same cadastral map and population census data.

6. Geovisualisation: Population density, property tax and occupations

Cartographic visualisation is a vigorous way of presenting spatial data. The most common types of thematic maps are choropleth maps and proportional symbol maps. Choropleth maps are particularly useful for visualising relative amounts, like percentages, densities and rates. Proportional symbol maps are particularly suitable for visualising absolute amounts or numbers by proportional symbols like circles scaled to the size of the absolute numbers. These basic thematic mapping methods will be illustrated with some examples using the digitised cadastral map of the inner city of the Dutch city of Leeuwarden of 1832 in combination with the digitised individual record data of the Leeuwarden population census held from 18 November to 31 December 1839. The population census of 1839 includes data on sex, age, marital status, place of birth, religion, and occupation. According to the population census of 1839 the total population of the city of Leeuwarden was around 23,400 inhabitants (ranking the ninth largest city in the Netherlands at that time). Around 80 percent of the population lived in the inner city (within the moat). The population density was highest near the fortifications as already shown in the choropleth map in Fig. 1b.

The cadastral ledgers accompanying the cadastral maps include besides data like names of the owner(s) and type of property (dwelling, school, church, yard, garden, etc.) also the taxable value of the premises. Fig. 3 presents another choropleth map of the taxable value of all occupied parcels in the inner city. The spatial pattern looks very similar to the spatial pattern in the population density map from Fig. 1b. In general, population density is high near the fortifications, where taxable values are low and parcels small. Population density is low in the city centre where taxable values are high and parcels large.

Another commonly used type of map is the proportional symbol map, a map type to display for instance absolute population numbers, like the number of people living in a dwelling. The population census of 1839 includes occupational data. Around one third of

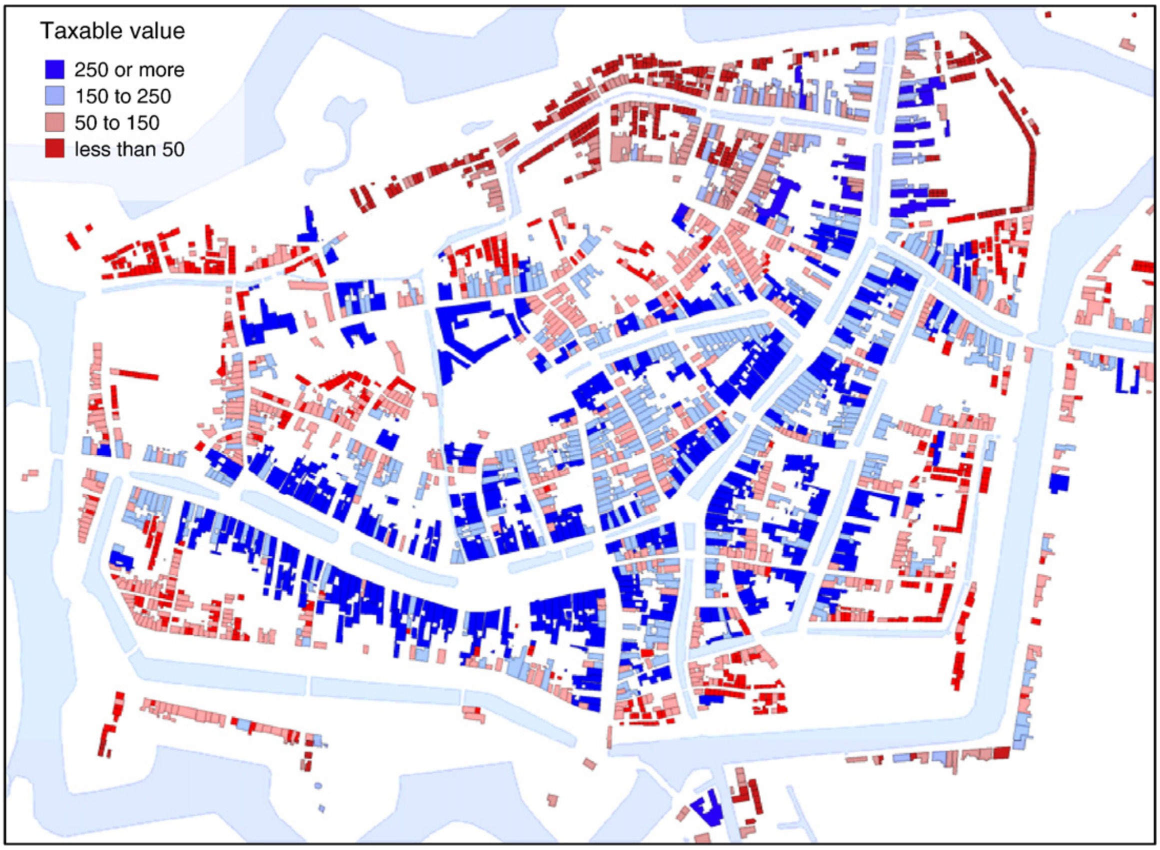

Fig. 3. Taxable value of all premises according to the cadastral ledgers of proprietors, Leeuwarden, 1832.

the person records have occupational titles added. The rest of the population, mainly women and children, have no occupation mentioned. The occupational titles were standardised and coded according to the Historical International Standard Classification of Occupations (HISCO; see Van Leeuwen, Maas, & Miles, 2002). The most common occupational titles refer to labourers and housemaids. The map in Fig. 4 shows the spatial distribution of the population by occupation for four selected occupations from varying social classes, viz. (male) labourers, housemaids, physicians and judges. The lower class labourers lived near the borders of the inner city in the densely populated areas with the smaller dwellings. The physicians and judges, belonging to the upper class, mainly lived in the less densely populated city centre, with the larger premises. However, the many lower class housemaids usually lived at the premises of the upper and middle class families by whom they were employed, that is in the city centre. The maps on population density, taxable value and occupations all together reflect the living conditions in the city, where the upper (and middle) class mainly lived in the larger and expensive housing in the centre and the poor in the small and cheap housing on the outskirts except for those who lived with their employers.

Although choropleth maps and proportional symbol maps are very powerful ways of thematic mapping, they also have their limitations and drawbacks. Choropleth maps and proportional symbol maps are not suitable for instance for visualising flow data, like migration flows. Flow maps should be used instead. Particularly choropleth maps can sometimes be somewhat misrepresenting by visually emphasising large areas over small areas. Using so-called area cartograms can be a better solution in such cases (see for instance Dorling, 1994).

7. Exploratory spatial data analysis: Religion

Exploratory spatial data analysis aims at finding or comparing spatial patterns by describing and summarizing spatial attribute data using spatial statistical techniques (or geostatistics). These spatial statistical techniques can be used to identify for instance spatial centres, spatial distributions, spatial clusters (or hot spots), spatial outliers, or spatial patterns of clustering or dispersion. Some basic spatial statistics will be illustrated with some examples again using the digitised cadastral map and population census data of the city of Leeuwarden. The structure of the population in Leeuwarden by religious

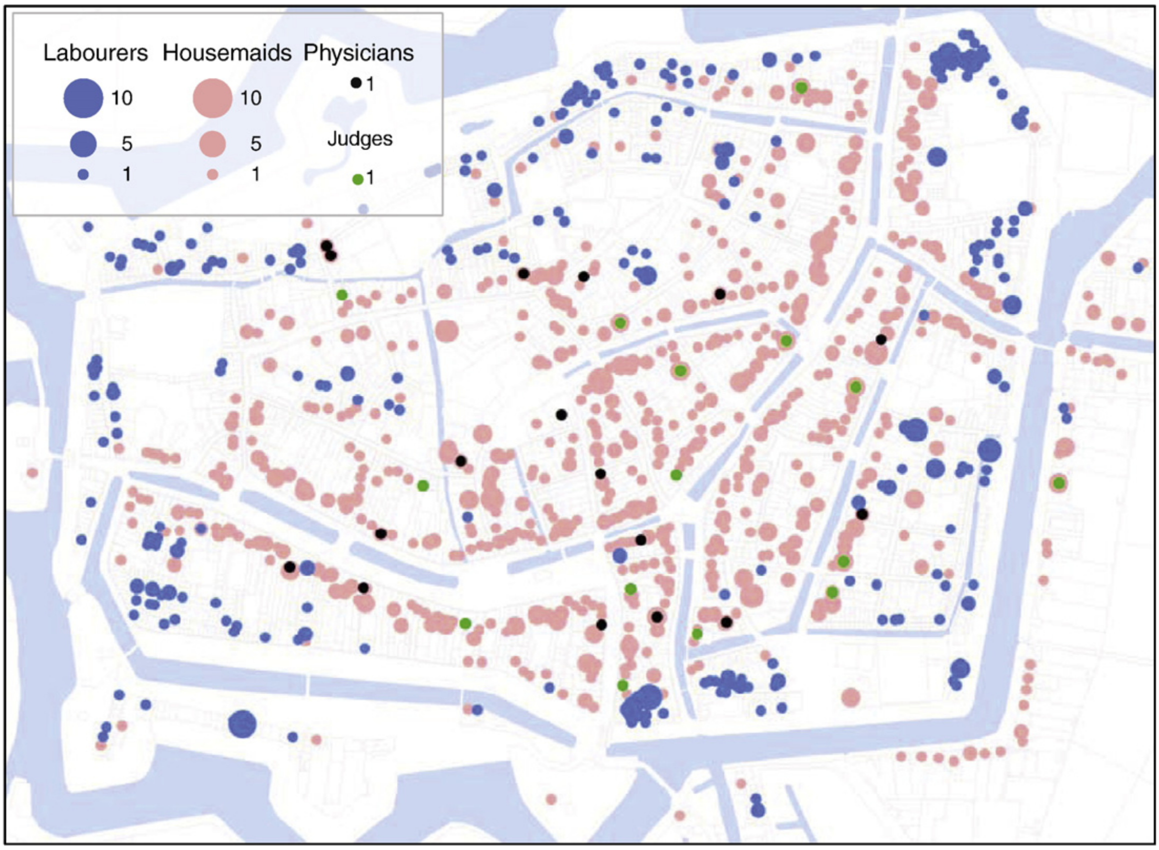

Fig. 4. Number of male labourers, housemaids, physicians and judges by dwelling according to the Leeuwarden population census 1839.

denomination in 1839 is dominated by the Protestants. Around 77% of the city population is Protestant, another 18% Roman Catholic, and 5% Jewish. Fig. 5 shows a choropleth map of the spatial distribution of the smallest religious group, the Jewish population. One can notice the spatial concentration of the Jewish population around certain streets. However, how does this compare to the other religious groups in the city? A relatively simple measure is the spatial mean, which calculates the centre of gravity of a set of locations by averaging both the longitude and latitude coordinates. To calculate the spatial mean of all the persons of a specific religious denomination, all persons get assigned a single location of residence in one spatial coordinate point (the centre of the dwelling). The spatial means result from averaging all longitude coordinates and all latitude coordinates of all the persons of that specific religious denomination. Fig. 6 displays the spatial means for all three denominations. The spatial means of the Protestant and Catholic population are separated by around 65 m, whereas the spatial mean of the Jewish population is around 120 m away. However, spatial means lack information on the spatial distribution of the places of residence. Like in regular statistics one can compute a standard distance, that measures the degree to which spatial points are concentrated or dispersed, visualised by a circle around the spatial mean. A drawback of the standard distance is that it lacks information on the direction of the spatial distribution. The standard deviational ellipse captures both the spatial distribution around the centre and the direction of that spatial distribution (Gong, 2002). Fig. 6 displays the standard deviational ellipses for all three denominations as well. The map shows that the Jewish population is indeed much more concentrated than the Catholic and Protestant population. Both direction and size of the standard deviational ellipse are quite different from the other groups. The standard deviational ellipse of the Jewish population stretches out a maximum 300 m from the spatial mean, only half the distance of the other two ellipses.

8. Spatial modelling and regression: Infant mortality

Beyond analysing spatial patterns in a descriptive way as shown above, spatial analysis methods and techniques can also be used to examine and quantify relationships between variables. Such advanced spatial analysis methods and techniques aim at explaining spatial patterns by using advanced spatial modelling, like spatial regression models, spatial interaction models, and

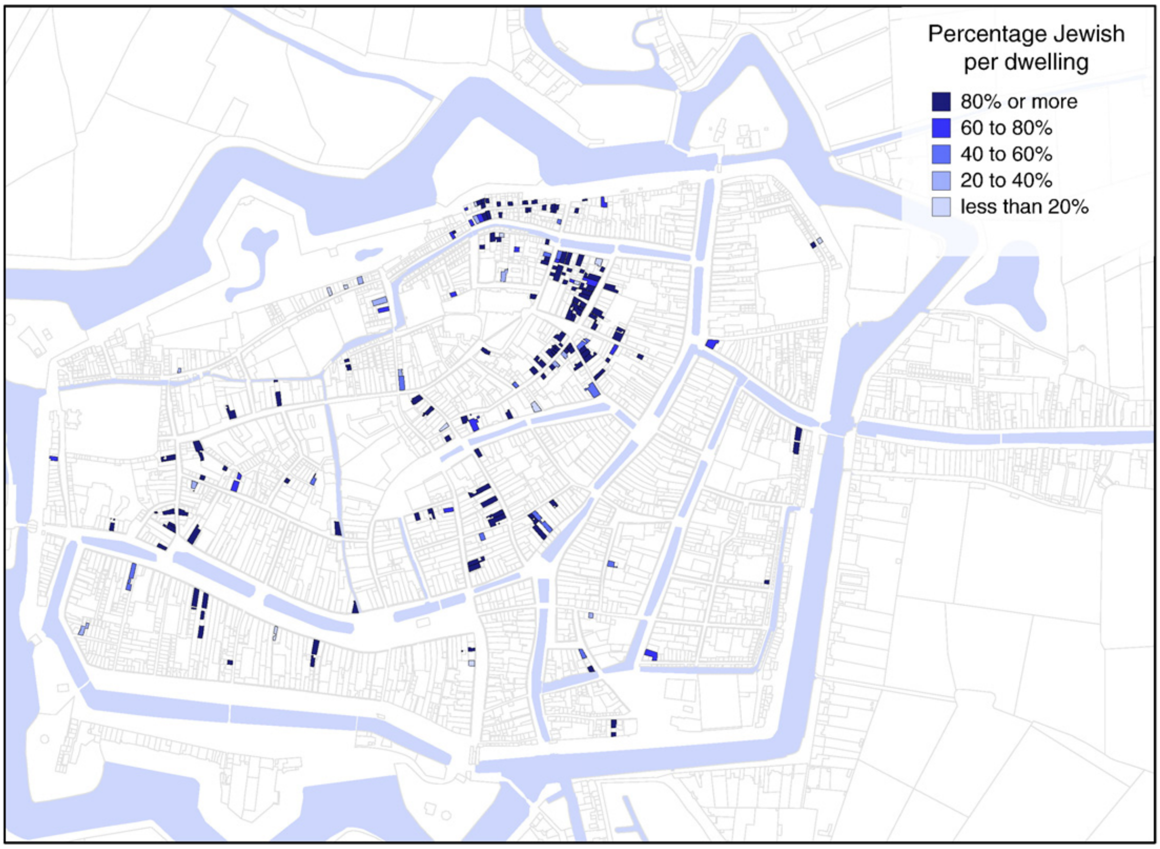

Fig. 5. Percentage Jewish population by dwelling according to the Leeuwarden population census 1839.

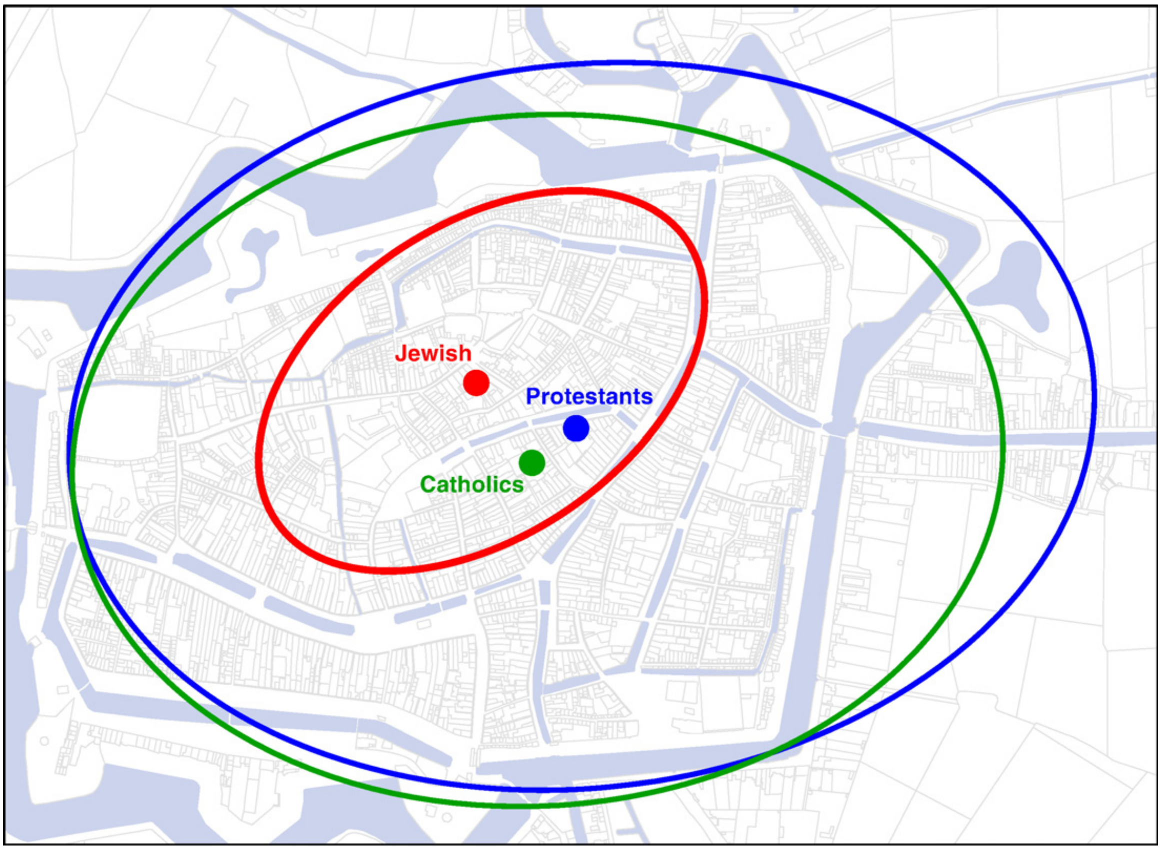

Fig. 6. Spatial means and standard deviational ellipses of the places of residence of the population by religious denomination according to the Leeuwarden population census 1839.

spatial simulation models (see for instance Anselin, 1988; Anselin, 2003; Chi & Zhu, 2008; Fotheringham et al., 2002; Longley & Batty, 1996). A somewhat simplified example of a spatial regression model applied to infant mortality is illustrated with again using data on the city of Leeuwarden. Three data sources were combined: the cadastral map of Leeuwarden 1832, the Leeuwarden population census 1839, and birth and (infant) mortality data from the Leeuwarden Register of Births, Deaths and Marriages in 1839–1840. Since there is no administrative link between the population census and the Register of Births, Deaths and Marriages, all birth records and infant mortality records referring to births in the period 1839–1840 from the Register of Births, Deaths and Marriages were linked by first and last name matching of parents and children to the population census records of 1839. The total number of births was 1178 and the total number of deaths below the age of one was 174. Fig. 7 shows the spatial distribution of the births and infant mortality in (and near) the inner city of Leeuwarden.

Regression analysis often begins with exploratory analysis, like reviewing spatial autocorrelation and spatial heterogeneity (Chi & Zhu, 2008). A spatial statistic like Moran's I (Moran, 1950) measures spatial autocorrelation by the degree of linear association between a variable at a given location and the weighted average of the variable at its neighbouring locations. Moran's I ranges from −1 (indicating perfect dispersion) via 0 (a random spatial pattern) to +1 (perfect correlation). The value of Moran's I for spatial autocorrelation between infant deaths and births is 0.047 (significant at 5% level), indicating indeed some spatial autocorrelation in the dataset. A spatial regression model is able to account for spatial autocorrelation. Two popular types of spatial regression models are the spatial lag model and the spatial error model (Anselin et al., 2006; Chi & Zhu, 2008). Spatial lag models model spatial autocorrelation by a linear relation between the dependent variable and the associated spatially lagged variable. Spatial error models model spatial autocorrelation by an error term and the spatially lagged error term. In illustration a spatial (logistic) regression model is fitted with a binary independent variable (infant died before the age of one or not) and several independent variables derived in line with other studies on infant mortality (see for instance Van Poppel, Jonker, & Mandemakers, 2005). The independent variables available from the population census data include:

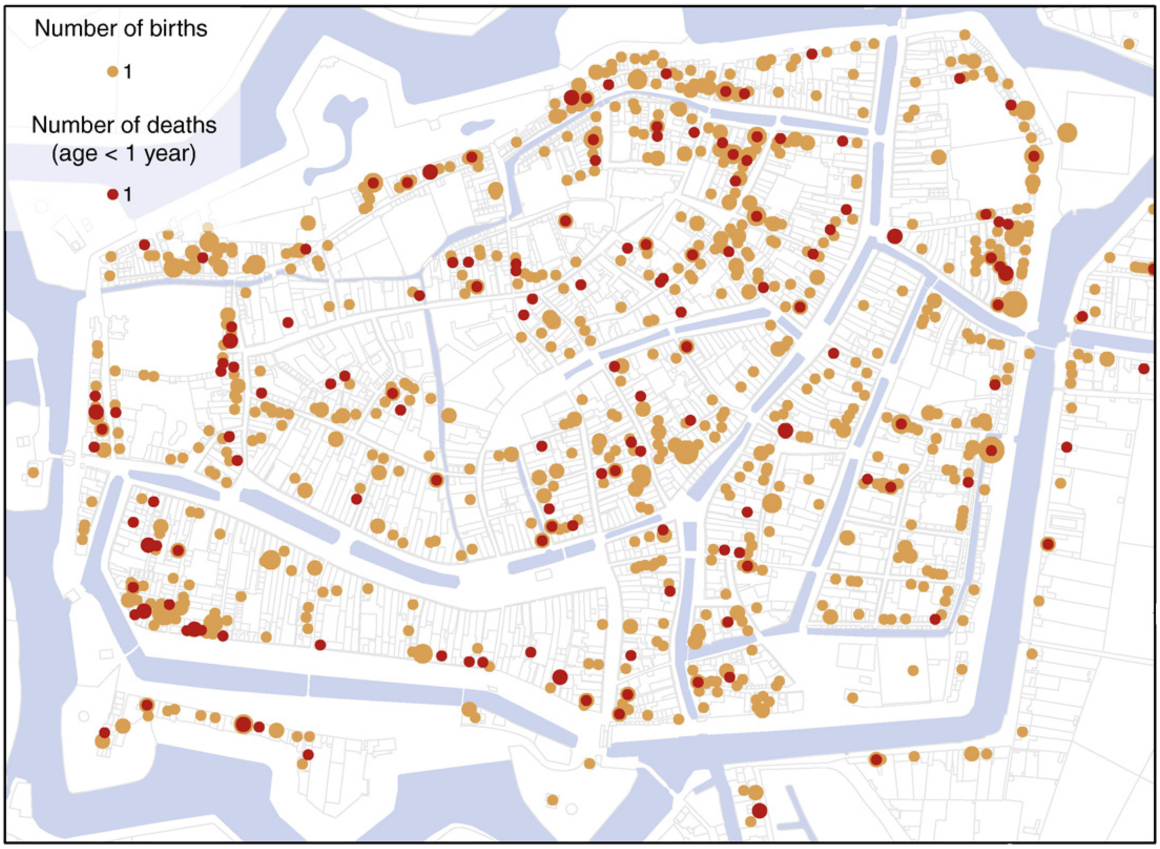

Fig. 7. Number of births and infant mortality by dwelling according to the Leeuwarden population register, 1839–1840.

socio-economic group (upper class, middle class, skilled labourers, semi-skilled labourers, and unskilled labourers; according to the condensed classification based on Van Leeuwen & Maas, 2005), sex of the child, age of the mother at birth, labour force status of the mother (occupation or not), marital status of the mother (married or not married), and season of birth. Table 1 presents the estimated results of the spatial regression model.

The estimation results of the standard model are in general in line with the results of other studies on infant mortality in the Netherlands in the same region (province of Friesland) and period (see Van Poppel et al., 2005). Infant mortality is lower for the upper class, lower for girls, lower for children born in marriages, lower in the summer season, but higher for mothers with an occupation. The standard spatial regression model provides some additional statistics. The Moran's I, for spatial autocorrelation in the error term, is close to zero and not significant. The Lagrange multiplier-lag and Lagrange multiplier-error indicate whether the spatial regression model is likely to be specified as a spatial lag model or a spatial error model. However, as expected because of the non significant Moran's I, both statistics are neither significant. For the sake of completeness results of the estimations for spatial lag model and the spatial error model are given in Table 1 as well, but they are very similar to the standard model. Apparently, the independent variables used in the model pretty well explain the spatial autocorrelation in the data.

9. Summary and discussion

In historical demography research interests more and more shift towards studying longitudinal microdata at the level of persons and households. Several projects develop large historical databases with individual and household microdata. Studying spatial patterns and trends at the microdata level requires similar detailed spatial data, like small-scale geographic coordinates and maps. Historical cadastral maps can be a very useful source for these types of spatial data. As an increasing range of geospatial data and tools, like geographical information systems (GIS) and geospatial analysis methods and techniques, have become available, it also becomes easier to combine, link and analyse microlevel demographic and other socio-economic data within a spatial context. Spatial analysis methods and techniques range from relatively easy visualisation in maps and applying basic spatial statistics to more advanced spatial modelling. However, preparing

Table 1
Spatial regression models for infant mortality in the Dutch city of Leeuwarden in the period 1839–1840 (N = 1178; Events = 174).

Variable	Standard model	Spatial lag model	Spatial error model
Socio-economic group			
Upper class	−0.098 [a]	−0.097 [a]	−0.097 [a]
Middle class	−0.003	−0.003	−0.003
Skilled labourers	−0.018	−0.018	−0.018
Semi-skilled labourers	−0.022	−0.022	−0.023
Unskilled labourers	0.000	0.000	0.000
Sex of child is female	−0.082 [a]	−0.082 [a]	−0.083 [a]
Age of mother	0.002	0.002	0.003
Mother has occupation	0.064 [a]	0.063 [a]	0.063 [a]
Mother is married	−0.068 [a]	−0.068 [a]	−0.068 [a]
Season of birth			
Summer	−0.077 [a]	−0.077 [a]	−0.078 [a]
Autumn	0.017	0.017	0.016
Winter	0.013	0.012	0.012
Spring	0.000	0.000	0.000
Spatial lag		0.032	
Lambda			0.040
Constant	0.188 [a]	0.183 [a]	0.187 [a]
Moran's I (error)	0.003		
Lagrange multiplier-error	0.076		
Lagrange multiplier-lag	0.112		

[a] Significant at 5% level.

historical paper cadastral maps for proper use in geographical information systems and geospatial analysis methods and techniques is a difficult and time-consuming task. Paper maps first have to be digitised to digital raster images and next these digital raster images preferably have to be vectorised (converting lines and symbols to vector objects) and geo-referenced (assigning geographical coordinates) at a very detailed, small-scale, level. To be able to study spatio-temporal trends one even needs several maps in time to capture the changing spatial context. Another difficulty is linking different data sources. Cadastral registration numbers are not necessarily the same as house numbering in population censuses and population or other registers or surveys. Neither are registration numbers always consistent in time. Historical data sources, both maps and microdata, might also have got (partially) lost. But once several linked spatial and other data sources are available they offer challenging opportunities for historical demographic research. This study showed some examples of combining several historical microdata sources and the way spatial analysis methods and techniques can be used to analyse those data. The examples of the Dutch city of Leeuwarden improve understanding of the spatial context of the population, the socio-economic structure and religious orientation. As demonstrated with population density, cadastral maps can even tell a different story than maps aggregated at the level of city districts.

We are still a long way from nationwide and long-time covering geographical information systems based on cadastral maps. From the perspective of historical demographic research the most interesting spatial areas certainly are the densely populated areas. From this point of view focusing on digitising urban areas would be of particular interest to historical demographers. Unfortunately, the densely populated regions and their attendant large number of parcels and dwellings, are the most time-consuming to digitise.

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The digital 1839–1840 birth and infant mortality records of the Leeuwarden Register of Births, Deaths and Marriages were downloaded from the online database provided by *Tresoar, the Friesland Historical and Literary Centre*.

The original scan of the cadastral map of 1832 used in Fig. 2a and b was provided by the Regional Archive of Woerden. The map data used in Fig. 2d are from the Dutch Land Registry Office (*Kadaster*) dataset called *Kadastrale kaart 2004* deposited with Data Archiving and Networked Services (DANS; persistent ID: *urn:nbn:nl:ui:13-oxg-wgy*).

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