Cartography and historical demography: The Historical SDI of the City of Madrid around 1900. (**HISDI-MAD)**

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Abstract

The Historical Spatial Data Infrastructure (SDI) of Madrid (**HISDI-MAD)**, joins together sociodemographic data and historical cartography for the city of Madrid, around 1900, representing a large number of sociodemographic variables at a level of detail only achievable with current individual level data and present day SDI systems, but not done so far with historical data for the case of a big city like Madrid, which in 1900 had 500,000 inhabitants. The base map used, primarily, but not exclusively, is the "Map of Madrid" carried out by the Spanish cartographer Facundo Cañada in 1902, whose original copy is preserved at the Center for Humanities and Social Sciences at the Spanish National Research Council (CCHS-CSIC). Related Cartography, aerial photography and ortophotography is used to cover the period 1860-2012. The sociodemographic information is derived from the Longitudinal Historical Demographic Dataset for the City of Madrid which is also carried out at the CCHS-CSIC (LHISTDATA-MAD).

This is a collaborative project between the CSIC and the Department of Statistics of the City of Madrid and from the geospatial perspective, was carried out according to INSPIRE (Infrastructure for Spatial Information in Europe) regulations and the technical specifications for interoperability OGC (Open Geospatial Consortium). The **HISDI-MAD** was created to structure, display, publish and share, through a GIS (Geographic Information Systems) Internet platform: historical maps of Madrid, the evolution of the urban space and the sociodemographic characteristics and differentials within the City which are fundamental to understand the transformation of the new demographic and social regime that took place between late XIXth Century and 1930s Madrid, where the City reached 1,000,000 inhabitants.

Keywords: historical demography, historical maps, SDI, GIS, sociodemographic characteristics, WMS (Web Map Service).

1.- Introduction

The Historical Spatial Data Infrastructure (SDI) of Madrid (**HISDI-MAD)**, was created to give cartographic and added geospatial information to the sociodemographic data derived from the Longitudinal Historical Dataset for the City of Madrid (LHISTDATA-MAD). Although the HISDI-MAD it is a scalable project and will be also used for the analysis of urban development, buildings history and urban planning, the project was designed for the analysis of urban demography, primarily for the analysis of the effect of migration flows in a city like Madrid, specifically how migratory movements of any kind can affect demographic variables (fertility, marriage and death) in a big city and, on the other hand, the effect of the influx of migrants to health and charity institutions and how they influence overall mortality and other sociodemographic indicators of the capital. Secondly, this historical SDI has been designed for epidemiological analysis of different infectious diseases. To perform the analysis, we have chosen the period of years ranging from 1888-1935, for the sociodemographic information, a period with intense migration from the countryside to Madrid [1].

This sociodemographic information must be linked and displayed on a suitable cartographic database, thereby allowing subsequent spatial analysis work. The information generated in this project is of great importance not only for scientific analysis, but also for other stakeholders, such as the Institute of Statistics of the Community of Madrid, or the Department of Statistics of the City of Madrid, enabling them to not only to have a GIS where able to capture much of the socio-demographic information (health, epidemics, age structure, family size, occupation structures, educational level, etc..) but also allow them to join Population Register under construction today for more recent periods, with the data resulting from this project, therefore allowing not only the creation of a longer longitudinal sociodemographic dataset but also a longitudinal geospatial system with space use through time. This contribution will focus only on the construction of the HISDI-MAD part of the project, therefore only concerning geospatial information.

2.- SDIs and their application to demography and historical maps.

INSPIRE proposes a SDI model as the right technology solution to share and publish any type of geographic information in a digital platform [2], via the Internet that allows any user to represent much of the sociodemographic information to be generated with this project, allowing future use and general knowledge. Moreover, the demographics if listed in Annex III of the INSPIRE Directive as key thematic data to include in the SDI.

There are few initiatives in Spain related to mapping servers of historical maps (Fernandez-Wytenbach et all, 2007) [3], (González et all, 2008) [4]. These authors discuss the reasons why the use of SDIs in historical cartography has not spread between the institutions with good historical cartographic materials.

As to the use of SDIs with historical demographic georeferenced data, the application in Spain is practically nonexistent and it is emerging in other European countries such as the Netherlands, UK, Italy, Denmark or Sweden. From the point of view of GIS mapping and applied to historical demography, only few, mostly in the US, like for example the CPE-Chicago Public Health and Ecological Datasets http://www.cpe.uchicago.edu/publichealth/pub_health_data.html, have addressed the creation of a SDI for the size of a city such as Madrid. There are pioneering work conducted in the UK at the University of Portsmouth (http://www.port.ac.uk/research/gbhgis) [5] and work of great interest carried out at the Netherlands Interdisciplinary Demographic Institute (NIDI), (Http://www.nidi.knaw.nl/en/projects/270019/) [6]. Most of the studies are focused on the development of national GISs, including large amounts of information regarding the administrative boundaries' changes linked to large statistical databases that hold census data and other statistical information. These GISs usually contain data from the early nineteenth century to the present. Examples of such national historical GIS are the National Historical Geographic Information System (NHGIS) of USA https://www.nhgis.org/,http://www.fas.harvard.edu/~chgis/data/chgis/downloads/v4/datasets/, the Great Britian Historial GIS (GBHGIS) which holds census, vital registration and Poor Law data, labour market statistics, mortality statistics and information about changing boundaries of the major administrative unit, http://www.port.ac.uk/research/gbhgis/abouttheproject/ or The China Historical GIS which cover 2000 years of Chinese History http://www.fas.harvard.edu/~chgis/.

At the Center for Humanities and Social Sciences (CCHS-CSIC) through the Population Research Group at the Institute of Economics, Geography and Demography (IEGD) and the collaboration of the GIS Support Unit at CCHS, and the Department of Statistics of the City of Madrid, interested in the results that can be derived from this project, it was proposed the generation of a SDI containing a georeferenced historical cartography of Madrid for early twentieth century, through the georeferencing and vectorization of historical maps of sufficient quality, to be able to serve as an additional tool for geostatistical analysis, and diffusion of results and digital thematic cartography via a web service system of the Longitudinal Historical Demographic Dataset of Madrid (LHISDATA-MAD).

The original map used for this project, is the map of Madrid of Facundo Cañada 1902. The original map is preserved at the maps room at the Center for Humanities and Social Sciences. We proceeded to digitise a diverse collection of Madrilian maps for the period 1850-1950, which has supported the implementation of the georeferencing and that will be the basis for future SDI mapping. Among this type of documentation should be noted, the historical aerial photography for 1929 and 1956, and various maps whose originals are kept in the Planning Department of the City of Madrid, as the Map of Madrid for 1929 with a 1:2000 scale. With all this documentation a digital cartographic database has been created and has been linked to other databases developed within the LHISDATA-MAD projects, using a population-cartographic dataset model to join all the information.

This SDI will release information below district level (specifically block level and in some cases building level), so far the neighbourhood represented the smallest administrative division which has been reached with published data on a historical level.

3.- The original 1902 Map of Madrid.

The execution of large scale maps of cities has been one of the major objectives of cartography, to the extent these cartographies appear among the first attempts of all civilizations [7]

"The Map of Madrid and surrounding villages at the beginning of XXth Century" is the name of the reference map used for this project and was carried out by one of the most important military cartographers at that time, Civil Guard commander, Facundo Cañada López. This map of Madrid is dated in 1902. The execution of the map took four years. It is a map made on a 1:7,500 scale, and consists of six big pages which joined together form a continuous map of great detail (see Figure 1). This map was made from field work topographic data collections and information of cadastral data at that time in possession of the National Geographical Institute (at that time the Geographic and Statistical Institute) and other unpublished information donated by corporations or individuals.

It has contours lines every 5 meter, measured according to sea level in Alicante, which is the reference point for altitude measurements in Spain and small maps of surrounding villages coming in separate boxes within the map. The map was drawn by A. Bonilla in eight colours. For this map, the commander Facundo Cañada obtained the "The first Prize of the International Chamber of Industry, Commerce and Science of Madrid, 1902" [8].

A significant element of this map is that it shows for the first time, the estimated economic value of the land per square meter for the city of Madrid, whether it was a building or an empty space, making this map one of the most appreciated and important historical cartographic documents for cadastral purposes in Madrid.

Fig.1: Full Map of Madrid and surrounding villages at the beginning of XXth Century

This map has also a very extensive and detailed "Guide" with very diverse information of Madrid at the time, such as public schools and type of education given on those schools, alphabetical list of streets, roads, buildings and general directory of unique buildings, transportation systems network, alphabetical list of statues on public sites, etc., all properly referenced according to a grid drawn on the plane.

4.- The generation of the cartographic spatial database.

The Map of Madrid 1902 has geometric and topographic consistent basis, therefore the six big sheets of the map have been georeferenced to form a mosaic, creating a uniform picture quality image that can be published through an Internet map service.

The historical sociodemographic individual level information has postal address information (street name and number, and floor number and flat letter), therefore to link to the historical map of Madrid it was necessary to carry out a high accuracy georeferencing process which could guarantee the link between the sociodemographic and cartographic datasets with a joint data model system.

4.1 Georeferencing Process

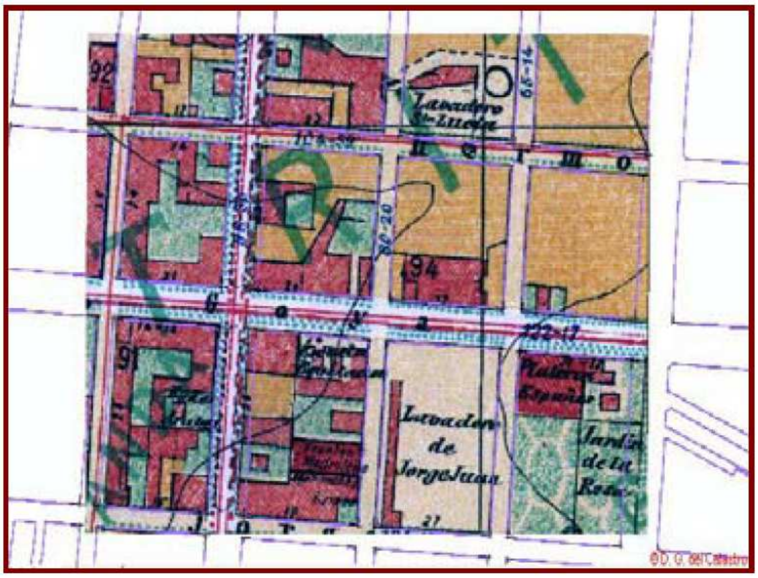
The georeferencing process has been long and meticulous to ensure the level of detail provided. The original historic map was done on paper, and subsequently has been scanned at 300 dpi. Each sheet of the map was divided on regular tiles (42 tiles per sheet = 256 tiles in total), with a little edge overlap, and it has been georeferenced separately and later on it has been created a mosaic of tiles. Finally a colour balancing process has been applied. Each tile has at least 30 or 40 control points, and the transformation function used was a first order polynomial, since a higher degree polynomial function could produce distortions caused by the geomorphology of the land on which the city of Madrid is placed

The level of accuracy in terms of RMSE (Root Mean Squared Error), gets even more complicated when dealing with old maps drawn on paper and hand-drawn, so it has been taken reasonable theoretical threshold, with an average value for all tiles of 6.8 pixels, which is a mean accuracy, in real field values, of approximately four meters.

The georeferencing process has been carried out at block level, taking reference points at the corners of clearly identifiable buildings. This step allows a better fit between historical maps and reference maps, although this increases significantly runtimes.

The reference map used for this process has been the aerial ortophotography PNOA 0.5m resolution from the National Geographical Institute and cadastral mapping service available through WMS (Web Map Service) provided by the General Directorate of Cadastre (http://ovc . catastro.meh.es /) [9] as shown in Figure 2.

Fig.2: Map georeferencing process with Cadastral WMS information.



A priori, it would be advisable to work with the ETRS89 system, because it is the new standard to be undertaken as mandatory by the cartographic production Centers from January 2015 (Royal Decree 1071/2007, of 27 July, regulating the official geodetic reference system in Spain)[10], but the fact that the map database resulting from this project will be capable of multi-temporal analysis with data from different dates, including current information has conditioned the construction of the SDI and it has been chosen to georefence the map in ED50, UTM, zone 30 and later on to transform from this reference system to ETRS89. Although, we need to take into consideration the increase in geometric inaccuracies that this procedure could has been caused.

The resampling method used was the cubic convolution and the final pixel size has been of 0.6 m (true ground) which is equivalent to a size of 0.08 mm on the map.

4.2 Map's mosaicing and balancing process

After the georeferencing of all tiles, mosaicing and balancing of the map has been carried out to finish the Map. This process was carried out as has follows:

1.- Mosaicing of all tiles forming each of the six sheets that make up the original map. For this we have used the "geometry-based seamline" method from ERDAS Imagine, processing the entire active area of each image. From the six resulting mosaics we have proceeded to develop the final mosaic of the entire map, the resampling method has been in both cases a cubic convolution.

2.- The scanned original sheets were affected by changes in the tone and lighting which have been dragged to the georeferencing and mosaicking processes. To standardize the visual characteristics of the final result colour and brightness corrections have been made at the time of editing the final mosaic. Thus, a filter has been applied to diffuse light imbalances between the six images. Then there has been a colour balancing for attenuating tonal differences. Finally, we have conducted a homogenization of the histograms.

3.- On the final mosaic we made an editing process and manual correction of major errors, generally located in areas of overlap between sheets

4.3 Vectorization process

The vectorization of the georeferenced map was carried out in order to be able to reference and represent temporal information of statistical records and conducting future developments of this SDI, and finally for the geostatistical analysis and dissemination of economic, sociodemographic and epidemiological changes occurring over the period 1888-1935, for this first stage of the project.

The vectorization method was designed with a twofold objective:

1. The digitization of blocks as geospatial analysis unit, that later on will have sociodemographic, economicm and epidemiological information associated derived from the twin Longitudinal Historical Dataset of the City of Madrid.
2. To generate an accurate street "geocoded" road networks, which allows any subsequent studies on "network analysis", with its corresponding topology to ensure network integrity. The vectorization process developed in this project has been based on work published by Emilio Gómez Fernández (Process to create lines of streets from Voronoi diagrams, also called Thiessen polygons) [11] which is available at the following Internet address: http://es.wikipedia.org:80/wiki/Archivo:Voronoi_centerlines_skeleton.gif

The process is based on automated procedures for generating street axes from topological layer of blocks by building the so-called Voronoi cells:

• Manual Scan of blocks and the assignation of a unique identifier.

• Converting block polygons to polylines.

• Converting polylines to an equidistant points layer.

• Drawing from here the Voronoi polygons.

• Assignment to these new polygons as an identifier for blocks from which it comes, through a spatial.

• Generalization of the polygons by the identifier field by dissolving contiguous lines.

• Conversion of the polygons on poly-lines again, thus obtaining the axes of the streets and preserving the polygons identifiers (blocks).

• The last step in the process of vectorization has been to apply a simplification process of lines, in order to eliminate irregularities in the layout of the axes of the streets.

5. Demographic Database. The Longitudinal Historical Dataset of the City of Madrid.

Even we will focus on this contribution mainly on the cartographic side of the project, this SDI incorporates the spatial dimension to the analysis of other series of sociodemographic, economic and epidemiological sources. To do this, a Longitudinal Historical Demographic Dataset of the City of Madrid is in the process of been created, by digitising population, civil registration and other registers of the city of Madrid for the period 1888-1935, when the city grew from a population of 539 835 inhabitants in 1900 to almost a million in 1930.

The sources provide a wealth of individual level information both demographic and socioeconomic and also epidemiological information coming from, mainly, hospital records. Like the census, the information is structured on households identified with a physical address. In the census, each household has, apart from this physical address, information about its members, with their full names, relationship, sex, age, place of birth, marital status, occupation, and in some cases the period of residence in the city apart of other socioeconomic information. The other registers also provide physical address therefore it is possible to link such information to the SDI.

The 1905 listings of inhabitants will serve as a reference and link to the other major source of demographic interest:

Civil registration. The data on deaths, births and marriages for the period 1888-1935 will be incorporated via a probabilistic linkage system, allowing rebuilding the lives of individuals and trace their life trajectories over time.

The wealth of information contained in these administrative records allow in-depth understanding of sociodemographic, economic and epidemiological phenomena, allowing the association of different types of events to geographic locations and individuals and households.

Additionally, the SDI includes several aggregated level databases for the city of Madrid, obtained through various sources, including Vital Statistics Statistical information, Statistical Yearbook of Madrid and other contemporary sources which are also included in the geographic information system that will allow the representation of different aspects of the Madrilian society and demography during early twentieth century.

For the final design of spatial database was essential to design conceptually an Entity-Relationship data model representing both the social and demographic reality of the time and the Historical cartography. To do this, we have chosen the UML modelling notation (Unified Modeling Language) [12], following the recommendations of the implementation rules of INSPIRE Directive.

6 The WMS Map HISDI-MAD.

The Center for Humanities and Social Sciences CSIC has developed an online geoportal that hosts the sociodemographic and mapping of the city of Madrid as part of the data set on "Demography and Population" of the general CSIC future scientific SDI. This is published by the OGC WMS standard [13] by the name HISDI-MAD and with additional information such as the guide and the information provided by the twin project LHISTDATA-MAD).

The layers of information that can be visualized with the Web service are varied (see Figure 3), with vector and raster information and referred to all to the 1902 Map:

• Vector Layers

1. Blocks
2. Singular Buildings and empty spaces.
3. Parks and gardens
4. The axis of the streets
5. Streets
6. Neighbourhood
7. Districts
8. Land use
9. Contour layers
10. Streams and water channels: Rivers, continuous water streams, irrigation canals, irrigation channels project, irrigation ditches, ponds.
11. Facilities of Interest: Sinks, toilets, picnic areas, wells, bridges of iron and masonry,
12. Standard and narrow railways lines in operation and planned electric tram lines and steam and animal power lines in operation and planned.
13. Highways of first order, second and third or built, under construction and proposed, roads, sidewalks or paths.
14. Map Grid
15. Urban Area

Fig.3: HISDI-MAD WMS.

• Raster Layers

1. Georeferenced Map of Madrid Facundo Cañada 1902
2. 1929 Map of the City of Madrid
3. Aerial Photography of Madrid 1929 and 1956.

4. Map of successive extensions of Madrid, with the distribution of districts and neighbourhoods in 1902.
5. Map of the most relevant neighbouring towns in 1902.
6. The distribution map with administrative terms, 1902.
7. (MDT) Model of the Digital Terrain of the city of Madrid.
8. Other Cartography from 1860 to 2012.

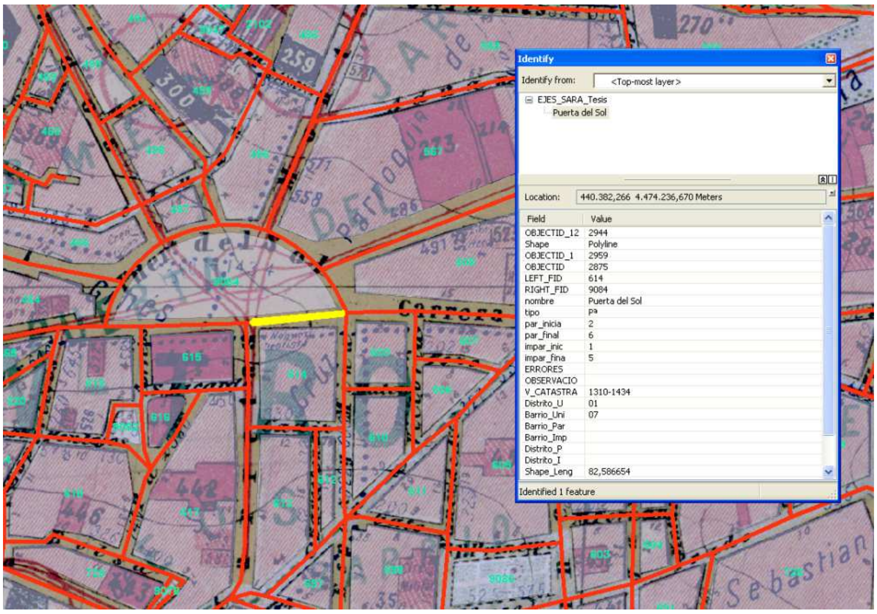
When making such a request of GetFeatureInfo type over the different layers, the user will receive the following information:

1. Blocks and empty spaces in the City: identifier, type, unique buildings contents if any, neighbourhood and district in which is located, as well as sociodemographic information associated with them, such as: number of inhabitants, sex, place of birth, age, marital status, occupation, date of death and cause, etc...
2. Singular Buildings: Building name, address and number in the directory guide accompanying the Cañada Facundo Map.
3. Parks and Gardens: Name, address and type (public or private).
4. Roads name stretch of road, type and numbering, even and odd
5. Streets: Street name, type and assessed cadastral value.
6. Neighbourhoods: Name and district to which it belongs.
7. Districts: District Name.
8. Contours: Altitude and coordinates of points which are equidistant.
9. Waterways natural and artificial: name and type.
10. Points of interest: sinks, toilets, picnic areas, wells, bridges of iron and masonry; coordinates and name.
11. Railways and tram lines: name, state, type.
12. Highways, roads, sidewalks: Name, order, state.
13. Facundo Cañada Map Grid: Grid coordinates on the plane.
14. Land cover in the map: the answer given is in a basic way: main occupation of the territory in the area of consultation, gives information on the type of occupation and area in Ha.
15. Urban Area: Type, downtown, expansion areas or suburb

7. Buildings coding system.

The spatial data infrastructure consists of a series of spatial information fields as reference vector layer. As we just showed, the street vector layer which is composed by the axes of the street which are linear sections with the width of the block, contains the following information: the name of the street, street type, initial even number (even number where the street begins), end even number, odd number odd start and end, number of the adjacent block number on the odd side of the street, neighborhood and district membership as odd or even side of the street. An example of this can be seen at Figure 4.

Fig. 4. Building coding system.



Because the program can not automatically generate a link between the demographic database and the Cartographic database at block level considering at the same time the left and right side of the street and because each street axis records the number range where numbering starts and ends, it was necessary to create a database linking process, which took into account the following criteria: even numbers goes up the street on the right and odd numbers is always on the left side. When joining even numbers are linked to the block which is located on the right side of the street of the same street axis and odd numbers are linked to the block on the left.

For the linking process of all the sociodemographic data to the spatial database was necessary to create a unique ID that function as a key spatial identifier. This identifier consists of 9 digits, of which the first five indicate the code of the street and the last four digits refer to the numbering. In this way we get a handle on the exact location of each of the buildings belonging to each of the blocks that form the blocks vector layer and on which later on we will link and display all the sociodemographic information.

In the process of linking demographic and cartographic data is necessary a similar data structure, that is to say, if the cartographic base unit of analysis is the building then the somedemographic database should be the same, so we must group the individual level sociodemographic database, apart of households, on buildings in which are recorded all individuals and their characteristics, and the number of the block to which that particular building belongs. Once both databases, cartographic and sociodemographic, has the same structure with a field in common "building unique identifying code" and the block code, this will allow us to make the link between the two databases at individual, household, building and block level, and from there we can identify and use other areas such as neighborhood or district, for example, or other kind or grouping.

8 Applications

Having a sociodemographic and epidemiological database associated with the digital cartography on a SDI offers countless possibilities for exploitation in historical and actual demography, from simple analysis to complex ones. At one end of the spectrum, it is possible to represent a range of demographic variables through thematic maps (on indicators such as birth rates, marriage rates, cause-specific mortality, etc..) for aggregate units such as neighbourhoods or districts. The level of detail of the SDI however, will enable the estimation and representation of those same indicators at block or block level, allowing much complete maps of the demography of Madrid. Although for much of the analysis it is not necessary to go down to such a level of detail, for other geostatistical analysis of epidemics, for example, this level of detail is relevant or the detection of clusters within the city on different characteristics, patterns of spatial segregation, daily evolution of epidemics in urban geography, etc... Moreover, and given the registers information available, it is possible to cross that information with other information on density, housing prices, occupation, socioeconomic status and other variables at block level.

9 A preliminary exercise displaying Infant Mortality Rate in Madrid in 1905

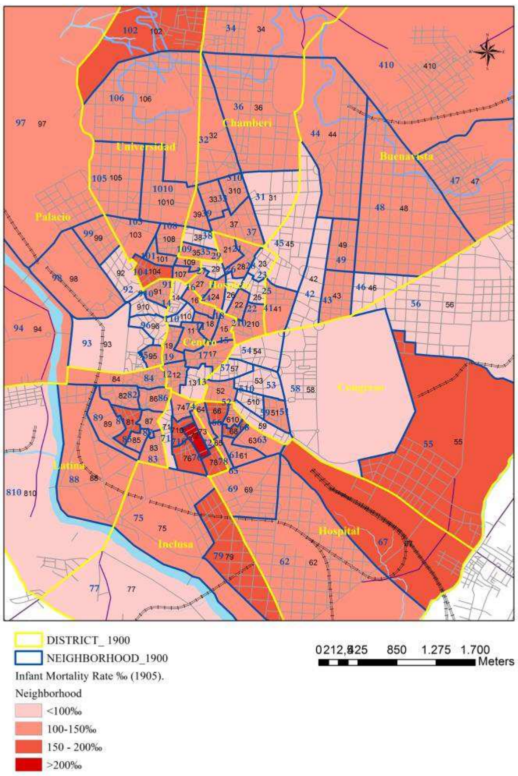
There is a long tradition of using health estimates for identifying deprivation areas within urban settlements. Within those health estimates, infant mortality rate have been one of the most used in the past, due to the crucial role within general life expectancy estimates. In this case we will proceed to carry out a preliminary exercise using the Longitudinal Historical Population Register of the City of Madrid for the year 1905.

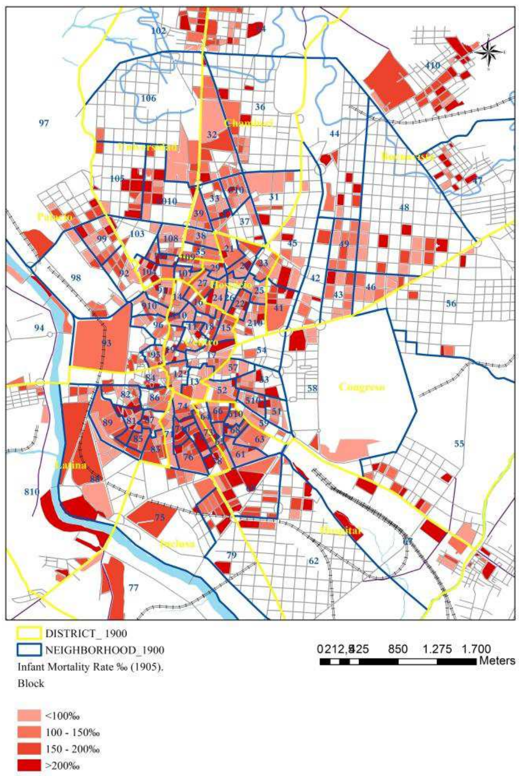
When attempting this exercise we face several problems. The first problem has to do with the correct codification of postal addresses. In 1905, 96% of postal addresses are coded; therefore 4% are not coded because there are streets without street numbers. 91,7% of the wards are coded. 8.3% loss due to the fact that the 1902 Map has some wards which do not have numbers, so even the street address is correct and coded, we cannot link it to the Ward because we miss the Information on the exact location of the number within a Ward or wards.

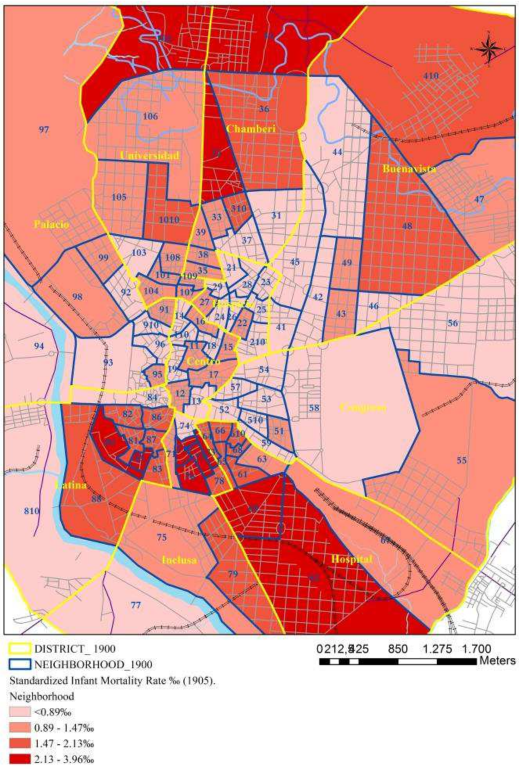
The second problem is linking the demographic data with the vital events. For 13% of Births and 8% of Deaths we don’t have correct address so they have not been linked to the map. This creates an overestimation of infant mortality and, probably, this overestimation is not evenly distributed within the city.

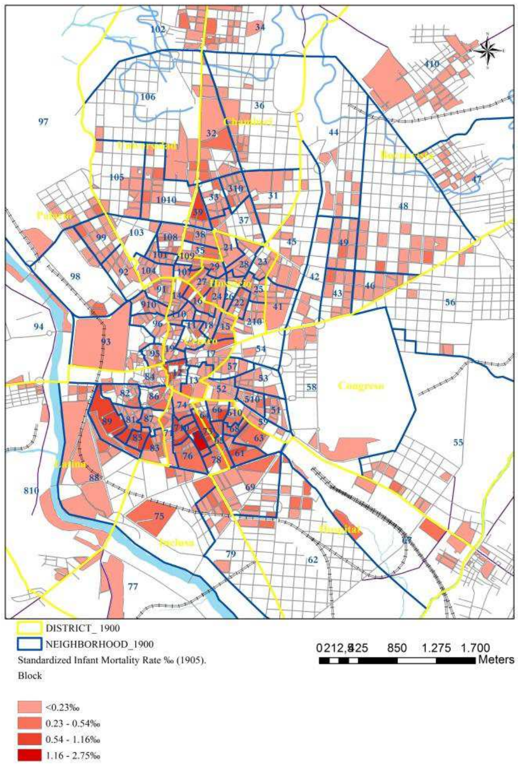
A third problem has to do with institutional mortality, that is to say mortality taking place in hospitals and welfare and charity institutions. Circa 25% of total deaths took place in Institutions (Hospitals, Foundling hospitals, Hospices etc.). In some cases like the Foundling hospital with almost 14% of all infant deaths in Madrid, could distort the representation of IMR in an urban area, due to the fact that infant mortality rate within the Foundling Hospital of Madrid was well above 700 per thousand level between 1890 till 1927. And most of the deaths taking place in these kinds of institutions reported only the place of death but not the place of residence, therefore making impossible, without the linkage with the listing of inhabitants, the identification of the place of residence. So we have estimated only infant mortality within households excluding institutional mortality. For that reason we have used only c3.630 infant deaths and all the non-institutional births c18000 for 1905.

The results of the analysis can be seen on the two following set of maps which displays firstly IMR at neighbourhood level (Madrid had 10 districts and c100 neighbourhoods), and at ward level and the second set of maps which displays Standardized IMR for the same levels.









The first conclusions that can be drawn from the data are that there are marked differences on infant mortality within the city. From levels well over 200 per thousand, to less than 100 per thousand. The average infant mortality rate in Madrid by 1905 was around 202 per thousand, higher if we include institutions and lower if we exclude them. The geographical distribution of infant mortality in the City follows much of the literature, and higher infant mortality is more present in poorest and more densely populated areas and especially in those with poor housing and areas where recent migrants to Madrid lived.

10 Conclusion

The HISDI-MAD is a research project that allows the representation, visualization, geospatial analysis and dissemination of indicators and sociodemographic and epidemiological variables on the internet, making possible temporal and spatial analysis of longitudinal population and epidemiological records, and represents a significant advance in the production of historical statistical information of longitudinal data, allowing the link between biographical trajectories based on individuals and families in their geographical area with other related geostatistical information, becoming a benchmark for future statistical and demographic analysis.

At the same time, it pretends to be a dynamic and scalable project at the Center for Humanities and Social Sciences and CSIC to advance in the future, towards the implementation of a National Science SDI (IDECSIC) with thematic data on "Demography and Population", highlighting the advantages of the use of geographic information technologies to integrate data generated by research institutions and groups under OGC specifications to ensure interoperability of the information. It is by itself an example of interdisciplinary cooperation between professionals from different fields (historical documentation, GIS, cartography, ICT, and demographics) and various public entities (City of Madrid, Universities and CSIC).

Finally, the implementation of a Geoportal on cartography and historical demography represents a significant contribution to the implementation of the spirit and philosophy of "sharing" of the INSPIRE Directive and an example of instruments that meets one of the priorities of the European policy.

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