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Cartographies on COVID-19 and functional divisions of the territory: an analysis on the evolution of the pandemic based on Basic Health Areas (BHA) in Castile and Leon (Spain)

Cartografías de la COVID-19 y divisiones funcionales del territorio: un análisis de la evolución de la pandemia basada en las Zonas Básicas de Salud (ZBS) en Castilla y León (España)

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Abstract

In the face of the confusion and uncertainty that COVID-19 has caused over the last year, Geography has proven to be a useful aid in the interpretation of the spatial dynamics that explain the transmission of the virus. Applied cartography and GIS analysis of epidemiological data have been consolidated as essential tools for interpreting the health crisis. This paper explores the

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usefulness of maps for the study of the evolution of the pandemic in Castile and Leon, one of the Spanish regions with the highest levels of infection and mortality. Based on the statistical variables of sick and dead people at the scale of the Basic Health Area (BHA), a first analytical approach is carried out by means of a sequence of dynamic maps during the first wave. Afterwards, a systematic study is carried out using thematic mapping for the period of the three waves, a period between March 2020 and March 2021. The analysis unravels the differential impact of the disease between rural and urban areas and reveals the problems of the mismatch between the functional divisions of the territory (BHA, as units of health analysis) and the scale of administrative management (municipalities, as the effective scale of action).

Key words: cartography; pandemic maps; GIS; spatial analysis.

Resumen

Ante el desconcierto y el desconocimiento generado en el último año por la COVID-19, la Geografía ha demostrado su utilidad para la interpretación de las dinámicas espaciales que explican la transmisión del virus. La cartografía aplicada y el análisis de datos epidemiológicos mediante SIG se han consolidado como herramientas esenciales para interpretar la crisis sanitaria. Este trabajo explora la utilidad de los mapas para el estudio de la evolución de la pandemia en Castilla y León, una de las regiones españolas con mayores niveles de contagio y mortalidad. A partir de las variables estadísticas de enfermos y fallecidos en la escala de la Zona Básica de Salud (ZBS), se efectúa una primera aproximación analítica mediante una secuencia de mapas dinámicos durante la primera ola. Posteriormente, se realiza un estudio sistemático mediante cartografía temática para las tres olas, entre marzo de 2020 y marzo de 2021. El análisis muestra el impacto diferencial de la enfermedad entre espacios rurales y núcleos urbanos y revela los problemas del desajuste entre las divisiones funcionales del territorio (ZBS, como unidades de análisis sanitario) y la escala de la gestión administrativa (municipios, como escala efectiva de actuación).

Palabras clave: cartografía; mapas de la pandemia; SIG; análisis espacial.

1 Introduction

The seriousness of COVID-19 immediately raised global awareness which led to sudden and traumatic consequences for people's daily lives. From the moment the World Health Organization (hereinafter WHO) received the first official notification of cases of pneumonia caused by a new coronavirus (31 December 2019) from the Wuhan Municipal Health Commission (Hubei province, China) until the disease was considered a world pandemic (11 March 2020), seventy days of bewilderment went by. The announcement triggered the reactions of the countries, which resulted in the adoption of uncoordinated and diverse measures. Three days after the pandemic declaration, the Spanish response was forceful and prompted a radical lockdown of the population as well as then ban all non-essential activities. This scenario of doubt and social insecurity gave rise to spontaneous and supportive responses of the population who put their capacities at the service of the country. At this early stage, everything concerning the disease and its consequences had yet to be studied, understood, explained and resolved.

Geography has participated in this process through the use of cartographic techniques and analysis to study the spatial behavior of the virus and with the aim of identifying the territorial dynamics that the disease may present. In Spain, different universities have put forward initiatives to develop research projects to map the processes of the transmission of the virus and analyze its impact during the last year. The Geographical Studies and Territorial Analysis Research Group of the University of Burgos (hereinafter GEOTER) has joined this trend of initiatives by carrying out analytical research using cartography applied to the study of the data on COVID-19 provided by the government in the Region of Castile and Leon.

This region, with a surface area of more than 90,000 km^2 and 2,248 municipalities, is one of the largest in Europe. This territory, which shows a contrasting population pattern, is inhabited by 2.4 million people. Most of its population lives in a dozen urban centers, while the rest of the rural territory has one of the lowest population density indices on the continent, reaching levels of severe depopulation (less than 10 inhabitants/km^2) in a large part of the area. This territory has been notably affected by COVID-19, and the disease has reached a relative impact higher beyond demographic average. By employing cartography as an essential diagnostic tool, this paper examines the impact of the disease in the region and the spatial patterns of infection dynamics.

The main goal of this paper is to develop a detailed spatio-temporal analysis of the impact of the pandemic in a Spanish region. However, we aim not only at showing the evolution of the disease through cartography, but also at contributing to a synthetic and comparative reflection in the national and international context. This study stems from the importance of maps in Health Geography and the interest of cartography in the analysis of the dynamics of the COVID-19 pandemic. To this end, a state of the art is presented on the usefulness of maps as tools for the spatial representation of health epidemics. More particularly, new applications of GIS tools in this process are identified. We reflect on the use of the new geo-dashboards as a basic technique of digital cartography applied to disease management and identify the geographical contributions that have so far been made from different Spanish universities to analyze the pandemic through the use of maps. This knowledge is finally applied to the specific analysis of the territory of Castile and Leon.

2 Geography, maps and health: COVID-19 cartographies

The transmission of diseases and their spatial spread has historically been one of the main problems faced by health management. Health problems have been conditioned by a multitude of factors related to the historical context, location and surroundings, environmental and climatic aspects, demographic and socioeconomic characteristics, cultural habits, etc. The geographical setting is a conditioning factor that determines health and the transmission of diseases that presents a complex spatial logic; even more so in the current context of globalization and its complicated geopolitical manifestations (Buzai & Santana, 2018; Méndez, 2020; Saracho, 2020).

Geography has been particularly attentive to the spatiality of health by considering not only the analysis of population health indicators in each territory, but also the study of life habits, medical care, accessibility to health services, their distribution and the approach to their causes and consequences. The territorial study of health has combined the geographical analysis of health services with the spatial consideration of epidemiology, analyzing the dynamics of disease transmission in different parts of the planet (Gurrutxaga, 2019).

Within this framework, the use of cartography has been consolidated as a useful applied tool; the spatial representation of disease behavior by means of thematic maps has become an essential resource for epidemiological study. Maps uncover otherwise unreadable information and allow to graphically visualize health processes and dynamics in the territory, as well as many other variables related to risk, fear, vulnerability, isolation or social fragmentation produced by these processes (Zusman et al., 2020).

Geography and cartography maps and spatial analysis of health— have served to visualize the spread of diseases and contributed to a better understanding of the patterns of virus spread as well as of the effects they lead to at different levels. Geographic analysis cannot solve the health problem caused by an epidemic, but cartographic techniques can provide a better understanding of its causes, its development and consequences in the territory (Van der Schee, 2020).

2.1 Spatial representation of epidemics: maps as tools for visualization, communication and analysis

The spatial representation of the effects of health epidemics through cartography supplies a visual language that allows to achieve communication and analysis results beyond the traditional study of data. The use of this tool applied to health dates back to the well-known London cholera map, a symbol of this technique drawn up by John Snow in 1854. This map enabled the development of useful hypothesis for the interpretation of the transmission of the disease thus giving rise to a method that has been amply used in all epidemics throughout the last two centuries (Buzai, 2020b; Dangermond & Pesaresi, 2018; Koch, 2005).

In the contemporary times we are in, socioeconomic progress, the evolution of transportation, the boost of connectivity and the creation of an increasingly globalized and interconnected society have fostered the spread of contagion dynamics. The 21st century has brought about a clear increase in epidemics spreading in several countries or even in most of the world, thus becoming pandemics (Méndez, 2020).

Faced with this situation, countries need to anticipate real-time and immediate tools that allow the continuous information management on the health crisis and facilitate government decision-making. To this end, addressing spatial influence of diseases from a triple dimension is deemed essential: demographic information (population characteristics), mobility patterns (paths and routes taken by people) and the characteristics of the infection transmission process (forms of contagion) (Buzai, 2020a).

Mapping the behavioral patterns of a disease in correlation with other spatial information can be determining when examining the cause of infection, identifying contributing factors and thereby strategically targeting intervention efforts to reduce or eliminate factors affecting the spread in the necessary locations (Lyseen et al., 2014, p. 114). With this approach, spatial analysis technologies and mapping of health data are an increasingly relevant dynamic in the scientific arena (Ahasan et al., 2020b; Franch-Pardo et al., 2020; Lyseen et al., 2014, p. 111).[1]

The leading role of GIS and the use of open data on networked platforms imply a number of advantages: the immediate and accessible analysis of data from multiple sources and their rapid mapping, the communicative visualization of pandemic information in cartography at different levels of detail, the spatial tracking of people with positive and asymptomatic results; the prediction of regional and local transmission; the incorporation of an analytical model related to the risk of exposure; the distribution and organization of health devices and specific resources; the support of socioemotional aspects and the elimination of panic among the population; and, finally and most importantly, the provision to public authorities of information integrated in a territorial analysis system (Dangermond, De Vito & Pesaresi, 2020, p. 203; Zhou et al., 2020).

Digital mapping using GIS technology for health emergency monitoring has different advantages that have already been addressed by the scientific community (Esri, 2020b; Dangermond, De Vito & Pesaresi, 2020, p. 201; Mocnik et al., 2020; Smith & Mennis, 2020). Out of the many advantages, the following should be at least considered:

- The use of GIS improves the capacity of information technologies to generate surveillance systems and achieve efficient responses, considering their capacity to analyze risk in advance (preventive health).
- The use of GIS is essential for the early detection of epidemics, providing immediate spatial information that allows effective control of the infection process.
- The synergy between GIS and statistical methods, interrelating different scales, is remarkable to restrain the advance of contagion waves and manage their decline (epidemic intelligence systems).
- The reflexive mapping of contagiousness helps to understand not only the location and distribution of a disease, but also to contextualize other related aspects and variables, its social repercussions and its interpretative complexity.

This applied GIScience approach enables an integrated territorial analysis and allows advancing the construction of insights for public health management, considering patterns of infection distribution, vulnerability, resilience, immunization, interdependence and care (Sparke &

1 Evidence shows that between 1991 and 2011, publication of research papers related to the use of GIS for the spatial study of infectious diseases increased sixfold. Out of a total of nearly 900 papers, more than 25 % use GIS as a methodological tool for analysis.

Anguelov, 2020). The contribution of spatial analysis is the basis for informed decision-making based on scientific evidence from the evolving geographic distribution provided by maps (Saran et al., 2020; Rosenkrantz et al., 2021).

GIS technology has brought about a clear paradigm shift in the possibilities of maps for territorial study and, in the context of digitization and communication technologies, it has become a reliable transmitter of knowledge. There are many examples of the use of digital cartography applied to health analysis, such as incidence of meteorological factors in the transmission of viruses, relationship between cases of diseases and temperature, wind speed, solar radiation, daylight hours or humidity, linking epidemic spread with communication networks and types of transport, case counts on maps according to different administrative or management limits, analysis of critical issues to identify geolocalized concentration of sick or dead people according to their location, identification, localization and distribution of vulnerable groups, etc. (Ahasan & Hossain, 2020; Cos de, Castillo & Cantarero, 2020b, 2021; Fatima et al., 2021; Li, 2021; Paez et al., 2021; Valjarević et al., 2020; Yalcin, 2020; Zhang et al., 2021).

2.2 Geo-dashboards: new GIS tools for the analysis of COVID-19

Considering these patterns, the technical capacity of GIS has been used to develop applied spatial analysis studies, and their recent integration into mobile devices has further popularized their effectiveness. The difficulties of interpreting their results have been overcome by integrating the map into "story map" platforms, where affordable templates are available to create and share thematic cartography using images, data, texts, audiovisual resources and other materials. Based on this concept of information interrelated with the map, the application of GIS tools to the analysis of health emergencies has succeeded in integrating cartography with a variety of statistical data. The COVID-19 pandemic has brought about a new tool that seems to be here to stay: geo-dashboards or control panels. Conceived with this approach of data integration and cartographic visualization, these dashboards display structured statistical and audiovisual information, geolocalized and integrated with maps. Geo-dashboards are an efficient example of an applied technique of the use of digital cartography as an integrating element of information at the service of public administrations (Esri, 2020d, 2020e; Dangermond & Pesaresi, 2018; Koch, 2005).

Geo-dashboards provide immediate visualization of map-centered data, allowing inexperience users to understand the analytics and spatiality of a framed phenomenon on a single, intuitive and remotely accessible (web-based) screen. About half of the websites communicating information on COVID-19 use the GIS-Web technique by incorporating a geo-dashboard (Bernasconi & Grandi, 2021; Pászto, Burian & Macku, 2020).

Since COVID-19 started to spread, different organizations and entities worldwide have been using geo-dashboards. Both the WHO and the World Bank use this type of panels to show the daily incidence of the disease, its spatial distribution and its incidence levels. Universities such as those of Virginia or Washington, organizations, foundations and research centers, as well as large companies and communication emporiums use geo-dashboards as key elements of their communication on the pandemic and the analysis of its effects. Without doubt, the best known and most popular initiative is that developed by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University in Baltimore. Figure 1 shows some of the major global geo-dashboards.

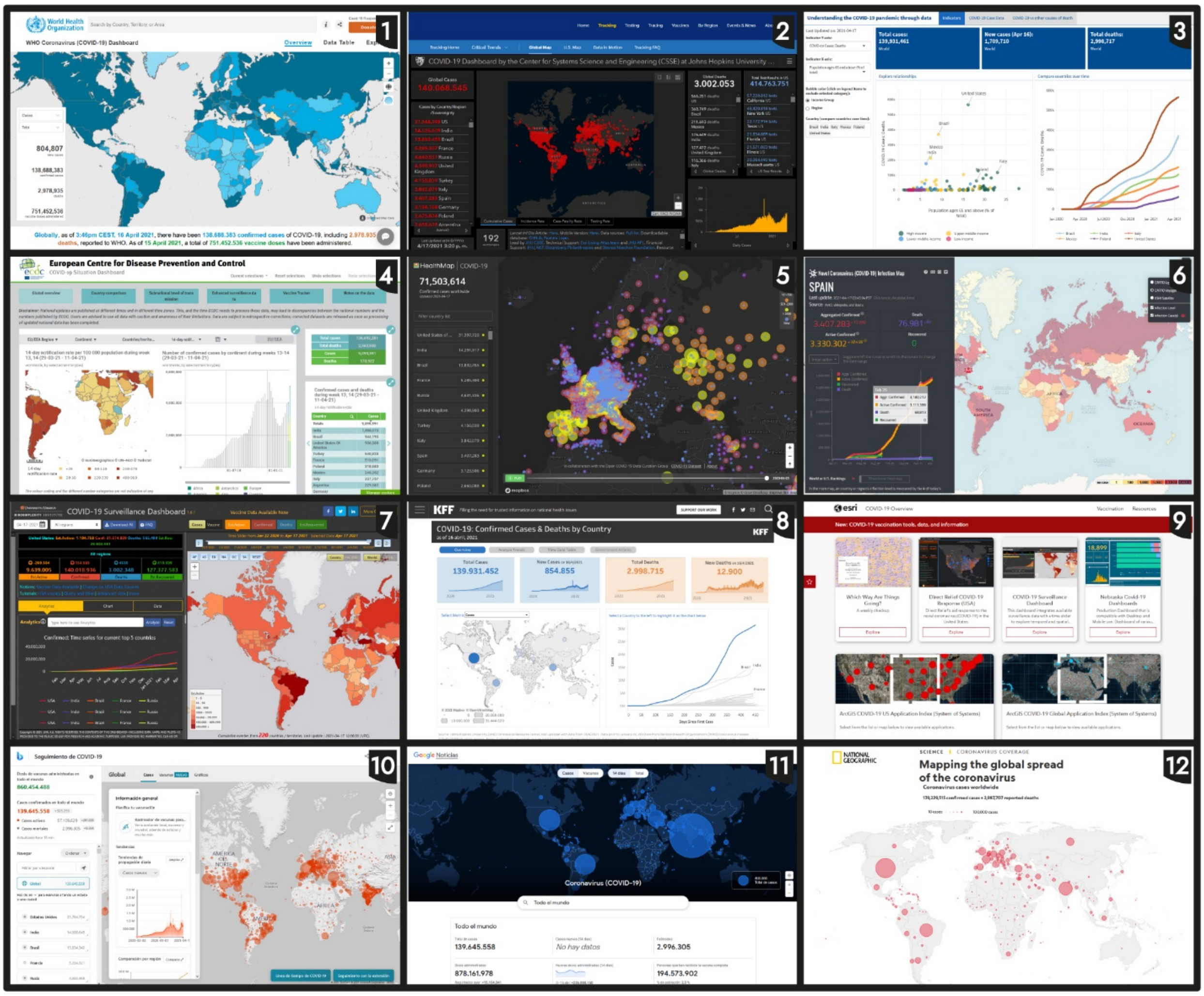
The success of this mapping has demonstrated the versatility and value of geographic information communicated through maps. These geo-dashboards have been replicated in practically all the countries of the world, thus becoming effective indicators of the health situation of each territory during the pandemic. Their use as tools for information and communication of the main COVID-19 data has been amply addressed in different studies (Chiluba & Dube, 2020; Esri, 2020b, 2020c; Guallart, 2020; Kamel & Geraghty, 2020; Müller & Louwsma, 2021; Pászto, Burian & Macku, 2020);[2] and it has been valued by the United Nations Global Expert Committee on Global Geospatial Information Management (UN-GGIM) as one of the most relevant technologies for decision making. It has been assessed that geo-dashboards convey the health status message in a clearer and more useful way than if this communication is done only through statistical data (Dong, Du & Gardner, 2020; UN-GGIM, 2020).

However, the use of geographic information technologies applied to epidemiological analysis and, in particular, this type of control panels, present some disadvantages. Scholars have critically considered that COVID-19 geo-dashboards are developed as "cultural artifacts" that use biopolitical technology and, therefore, offer a biased perspective of the territory which carries an ideological and propagandistic load. Although their efficiency as political and social tools for communicating the impact of the disease is undeniable, their relation to information partially managed by governments and their inability to adequately address the real consideration of

2 A selection of the world's leading COVID-19 geo-dashboards can be found at https://storymaps.arcgis.com/stories/a1746ada9bff48c09ef76e5a788b5910

inequalities produced by health crises have been questioned (Everts, 2020; Fenner, 2020; Rosenkrantz et al., 2021).

Figure 1. Main geo-dashboards (control panels) of COVID-19 on a global scale



1. World Health Organization (WHO): https://covid19.who.int/
2. CSSE at Johns Hopkins University: https://gisanddata.maps.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6
3. World Bank: https://datanalytics.worldbank.org/covid-dashboard/
4. European Centre for Disease Prevention and Control: https://qap.ecdc.europa.eu/public/extensions/COVID-19/COVID-19.html#global-overview-tab
5. Universities of Oxford and Harvard: https://www.healthmap.org/covid-19/
6. University of Washington: https://hgis.uw.edu/virus/
7. University of Virginia: https://nssac.bii.virginia.edu/covid-19/dashboard/
8. KFF. Global Health Policy: https://www.kff.org/global-health-policy/fact-sheet/coronavirus-tracker/
9. COVID-19 GIS Hub Esri: https://coronavirus-resources.esri.com/
10. Microsoft COVID-19 Tracker: https://www.bing.com/covid
11. Google COVID-19 Map: https://news.google.com/covid19/map?hl=es
12. National Geographic: https://www.nationalgeographic.com/science/graphics/mapping-coronavirus-infections-across-the-globe

Source: own elaboration

Likewise, other scholars suggest that the use of GIS in the COVID-19 pandemic has not yet provided results commensurate with the potential of this tool in the field of predictive analysis. Basically, maps have been used to visualize the distribution, sequence and evolution of confirmed cases or the number of deaths. However, it is possible to make progress in the possibilities of digital cartography and also predict specific locations of future outbreaks with greater statistical accuracy. In some countries and not without controversy due to the impact on personal freedoms— applications based on positioning have already been used thus allowing tracking not only of the affected person but also of other people in contact, facilitating possible quarantines (Ahasan et al., 2020).

On the other hand, the proliferation of mapping solutions available e to inexperienced users has led to the dissemination of a plethora of COVID-19 maps on the internet that disseminate unverified information, distort reality either intentionally or unintentionally— and sometimes generate the opposite effect intended by the use of GIS applied to health management. Similarly, some disease maps are misinterpreted because the spatial information is not always easily understandable and entails a certain cognitive overload, due to the inherent complexity of the data. Likewise, choosing the wrong map projection means that people may overestimate or underestimate the nature of the message conveyed by the map. It is not uncommon to find maps on the web that depict the pandemic situation in the same territory and reflect contradictory graphic evidence. The misuse of scales, proportions, symbols, colors and any other graphic elements on the map can generate enormous confusion among the general public for whom the cartography is designed. The mapping of health information requires enormous rigor in the treatment of the data. The application of GIS to health management entails a variety of problems that must be properly addressed in order to map responsibly (Field, 2020; Juergens, 2020; Kent, 2020; Mooney & Juhász, 2020; Zhang et al., 2021).

2.3 Mapping COVID-19 in Spain: geographic contributions from universities

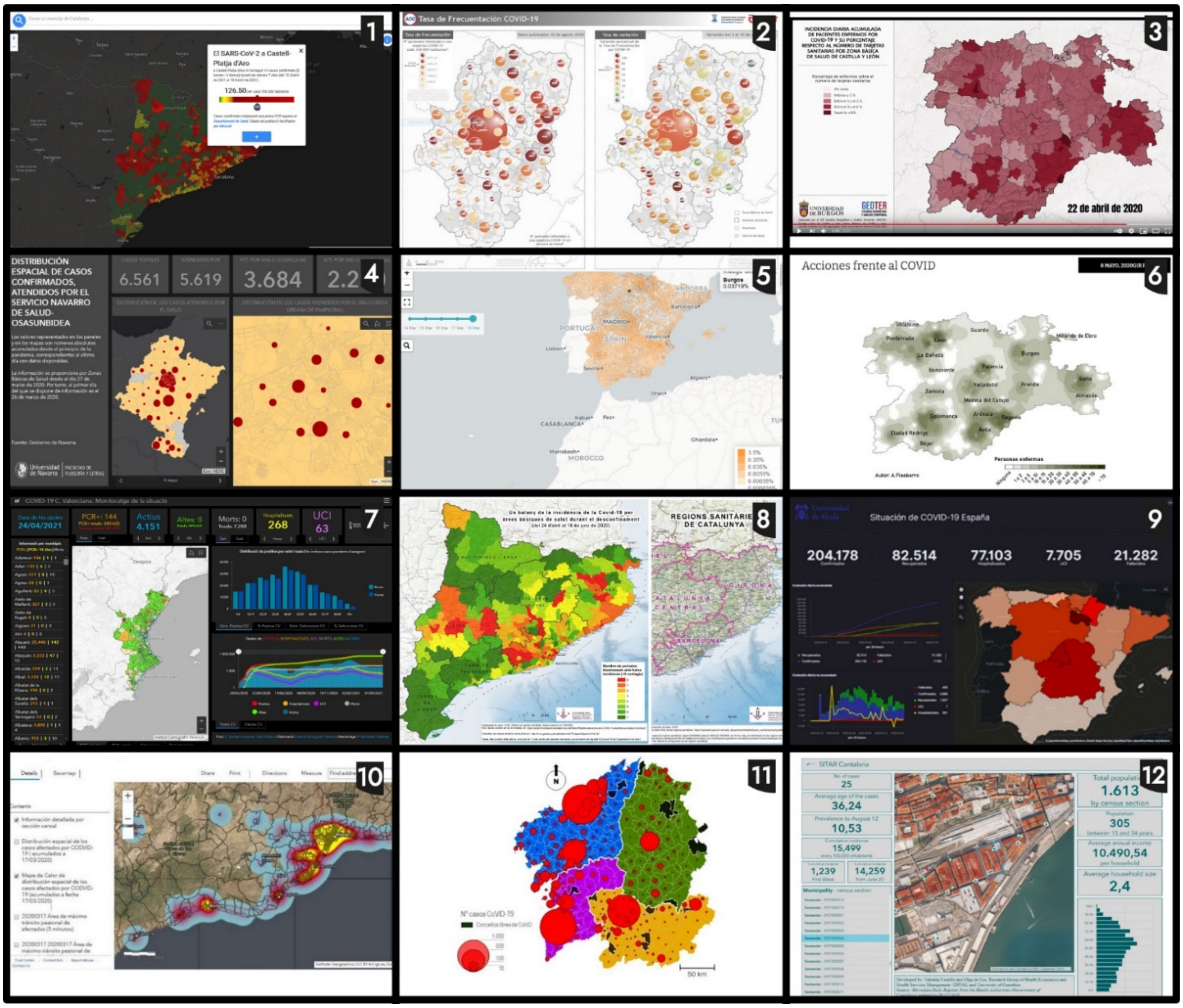
Spain reached a cumulative incidence of more than 3.4 million people infected by COVID-19 in April 2021. Information on the pandemic is publicly available thanks to powerful communication tools that integrate mapping and statistical data. At the national level, this information can be consulted through the panel of the National Epidemiology Center. Additionally, each region has developed webpages to monitor the evolution of the process from the first moments of the health crisis. Currently, there are plenty of sources of information that the public administration has been making available in relation to the impact of COVID-19 in the country (Cobarsí-Morales, 2020).

However, despite all this, there seem to be not enough models based on in-depth spatial analysis; models that allow the public authorities to consider an adequate diagnosis with sufficient territorialized information on the phenomenon. The study of the spatial distribution patterns of these cases has unveiled a lack of precise knowledge on the spatial transmission process of the disease. This has clearly affected the management capacity of regional governments, which have witnessed the inefficiency and the contradictory application of measures such as perimetral lockdowns, reduced schedules, curfews and mobility limitations. These needs have especially highlighted the relevance of responsible mapping (Cos de, Castillo & Cantarero, 2021).

With the aim of solving these problems and contributing to the improvement of the geographical study of the behavior of the virus to provide useful diagnoses to public administrations, several projects have emerged from different universities. A large part of these actions has been carried out from the geographical perspective, by offering its experience and knowledge, its scientific-technical capabilities and its resources related to GIS and cartography techniques to the service of the public authorities for the management of the health crisis. Figure 2 shows some of the initiatives developed by researchers from Spanish universities, such as the projects of Alcalá de Henares, Barcelona, Burgos, Cantabria, Girona, Lleida, Navarra, Málaga, Santiago de Compostela, Valencia, Valladolid and Zaragoza.

These universities have made available to the public administrations their analytical potential and their data processing capacity to develop studies on the spatial incidence of the virus. The common objective of all of them has been to work with disaggregated information at the microdata level, with unitary case reference in order to build spatial analytical models interrelated with the socioeconomic information in each territory. Many of these projects were developed in the first weeks of the disease. During this time, most of the universities involved set up platforms to disseminate the mapping obtained on network channels (websites, social networks and other repositories). In the last months, their results have been disseminated, in many cases as a consequence of the integration of collaboration networks among different entities (Zuñiga, Pueyo & Postigo, 2020).

Figure 2. COVID-19 mapping initiatives in different Spanish universities



1. University of Girona: https://mapscloud.udg.edu/covidmunicipis/

2. University of Zaragoza: https://zaragoza.es/sede/portal/coronavirus/geocovid19?refresh=yhttps://bit.ly/2RCPYqa

3. University of Burgos: https://www.youtube.com/channel/UCzFniyIR6WTnv0jahVnyvPw

4. University of Navarra: https://sites.google.com/unav.es/covid-19-navarra/contagiados

5. Rovira i Virgili University: https://covid-19-risk.github.io/map/spain/es/

6. University of Valladolid: https://albergueweb1.uva.es/gir_pangea/?p=1660

7. Polytechnic University of Valencia: https://icvgva.maps.arcgis.com/apps/opsdashboard/index.html#/3a3115ad642a4516b0928f21e395b32d

8. University of Lleida: http://www.geosoc.udl.cat/ca/serveiCT/mapes/

9. University of Alcalá de Henares

10. University of Málaga

11. University of Santiago de Compostela

12. University of Cantabria

Source: own elaboration

This has been the case of the project put forward by the Department of Geography of the University of Málaga which, since March 16, 2020, has made a call for voluntary participation to geographers of Spanish universities for the elaboration of COVID-19 risk cartographies in their respective territories. Under the title "COVID-19 transmission hazard cartographies in urban areas oriented to the application of anti-propagation measures", the Territorial Risk Analysis Research Group of the aforementioned university devised and launched this initiative which has gradually integrated geographers from 18 Spanish universities. The applied purpose of the project focused on the creation of a precise cartography that could be updated in real time for diagnosis, advice and rapid response capacity adjusted to the different situations that the Spanish cities may present. Its main goal was to establish comparative dynamics and to favor the integrated study of the spread of the virus in diverse territories. The project reflects the concern of geography in Spanish universities to map the transmission behavior of the virus as a useful tool for the analysis, diagnosis and strategic planning of decisions to be taken by health professionals and policy makers in charge of its management (Perles et al., 2020).[3]

However, the results of the initiative have been diverse and uneven, severely conditioned by the enormous difficulties in accessing the information provided by the administrative units responsible for data management. The need to meet the requirements of each territory has led these projects to develop very different methodologies and cartographic proposals. University research teams have persisted in the elaboration of cartographies, but most regional governments have not provided disaggregated unit data on cases affected by the disease. This has therefore hindered the possibility of developing more consistent spatial analysis studies, which would have allowed to cross-check the temporal evolution and spatial distribution pattern with other socioeconomic information at the microdata level.

The sensitive nature of the information and the fact that the data are provided in aggregate (by provinces, BHA or municipalities) has generally prevented the initial purpose of the detailed study at the urban micro-scale. Detailed data have only been obtained for the cities of Málaga, Santiago de Compostela and Zaragoza, which have allowed to pursue the project in its original approach of monitoring, prediction and transmission control based on the mapping of the foci of contagion in the neighborhoods in collaboration with the city councils. In the rest of the cases,

3 The working team of the COVID-19 cartographies project in Spain is made up of researchers from the universities of Alcalá de Henares, Alicante, Baleares, Barcelona, Burgos, Cantabria, Cádiz, Córdoba, Complutense of Madrid, Granada, Jaén, La Laguna, Málaga, Pablo Olavide, Santiago de Compostela, Seville, Valencia and Zaragoza.

the scale has been mostly municipal or health units, without a more detailed spatial image with precise localization of the cases. In fact, several universities announced on their project websites that the process of developing the cartographies had been abandoned due to the lack of an adequate level of spatial disaggregation of the information.

Thus, the result has been an expressive cartography of the main foci of contagion and trends in the spatial behavior of virus transmission, but that does not allow to identify the urban factors with which it is related at the microscale, nor determine the key areas for action to control the spread by applying targeted measures. This mismatch between the possible unit of spatial analysis and the evidence in health management, forced to refer to the detailed case, has highlighted the difficulties of geographical interpretation of the thematic study of the behavior of the virus, as well as largely conditioned the development of the cartographies, weighed down by the inconsistency between the units of health analysis and the administrative and management boundaries with real powers over the governance of the territory.

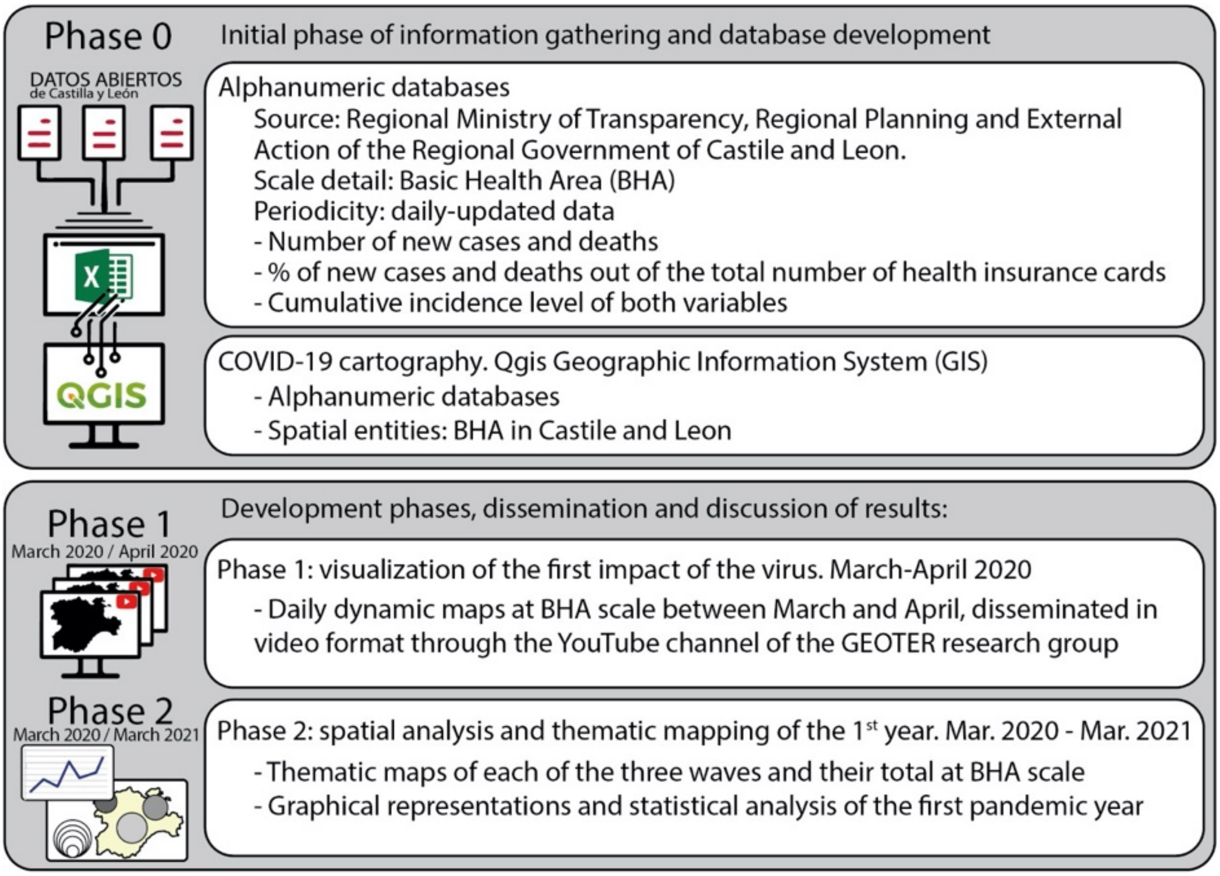
3 Case study, sources and methodology: mapping, health analysis and territory divisions

In this context, the GEOTER research group has developed during the last year a study on the evolution of COVID-19 in the Region of Castile and Leon. The project has been undertaken in two phases. Firstly, an early and rapid response initiative, in which a series of dynamic maps were produced to interpret the impact of the virus during the most intense phase of the first wave (March-April 2020). Secondly, a more detailed analysis of the evolution of the pandemic during the last year through thematic mapping, comparing the time sequence of the three waves (March 2020-March 2021). In both cases —dynamic maps for initial analysis and thematic mapping for detailed study—, the previously mentioned problem arose: the obvious mismatch between the health analysis units, which are used as a functional division in the territories, and the administrative divisions operating in each of them. This paper reflects on the difficulties of the representation of statistical information and considers this dichotomy between health analysis units and administrative management units. Under this condition, the sequence that comprises the provinces, the Basic Health Areas (BHA) and the municipalities in Castile and Leon are identified.

This study is based on the open data on COVID-19 provided by the site of the Ministry of Transparency, Regional Planning and External Action of the Regional Government of Castile and Leon. Given the unavailability of disaggregated statistical information at the municipal or microdata level, the existing variables at the BHA level were used. Specifically, statistical information has been tabulated on the number of patients and deaths reported in each of these units, as well as the levels of the intensity of the infection and mortality on the same scale. Rates and indicators have been calculated to obtain the relative incidence of the phenomenon in each phase of the pandemic (sick and dead people per volume of population, 14-day cumulative). In order to compare the region with the rest of the country, data from the National Centre of Epidemiology (hereinafter CNE) were used.

Based on these sources of information, and in the absence of previous solid hypotheses on the behavior of the virus, the study of the dynamics of this specific case develops an inductive methodology to formulate conclusions valid for generalization. Progress in the knowledge of the effects of the pandemic requires the pooling of studies in different territories to build behavioral patterns of the disease. With this approach, this study has integrated the information in a dynamic database associated with the *Qgis Geographic Information System* (GIS). In this open source and free software, the alphanumeric records of the disease incidence have been linked to the spatial geometries of each territorial unit, thus generating the thematic cartography presented at the intermediate scale of the aforementioned BHA.

Figure 3. Research methodology outline



Source: own elaboration

In Castile and Leon, the singularity of the use of Basic Health Areas (BHA) as an essential unit of health analysis has unveiled contradictions and differences in the management of the different areas in the region. The inconsistency between these units of analysis and their actual application to decisions aimed at controlling the pandemic taken at the municipal level has revealed a lack of real functional territorial delimitation, which has subsequently been transferred to the cartographic model.

The COVID-19 pandemic and the territorial-based mechanisms tested for its management have sparked the ongoing debate on the spatial-functional organization of the territory, i.e. the geometric rigidity of the limits and their operability for functional management. The classic assimilation of territorial delimitation with administrative divisions poses a contradiction between the consistency of this administrative boundary —the only management delimitation— and the functional inconsistency that this manifests for decision-making. It is a well-known fact that, above and below the political-administrative delimitations, there are territorial structures that serve organizational (basic health areas, educational districts, judicial districts, military regions, etc.) or functional criteria, such as regions or the territorialization of services (Ramírez & Reguera, 1994). However, these delimitations, which strictly adjust to their purpose, do not regulate the political decisions of territorial government because they lack the power to do so. The management of units adjusted to management criteria is practical for planning, although their direct translation to management can rarely be applied due to political and legal factors (Ortega Montequín, 2017). This dilemma has precipitated a discussion on spatial scales and the duality of functional *versus* operational delimitations; both converted into units of cartographic representation, differential in many cases. In other parts of the world, this debate has also played a leading role in the management of the pandemic (Valente Cardoso et al., 2020).

The emergency situation caused by COVID-19 has highlighted this contradiction. While the analysis of the pandemic has been carried out on basic units of analysis determined by the health division of the territory and its state at any given time (overload of care and hospital resources), the territorial management for the adoption of containment measures (restrictions on mobility and economic activities) has been of a state, regional, provincial or municipal nature, and has been obligatorily determined by the administrative boundaries with legal powers. This is the superiority of the administrative boundary, which, as stated by Ortega Valcárcel (2000), is the sphere of management, control, programming and planning, arrangement, and both functional and social attribution.

This has been particularly striking in the Region of Castile and Leon. From the beginning of the health crisis, this region decided to organize the analysis of the pandemic in accordance with the territorial basis of its health organization, reflected in the cartographic representation. The Basic Health Areas (BHA) established around each primary health care center in the region, have been the territorial basis to account for the scope and risk of the pandemic. This has given rise to a differential cartography with respect to the official mapping provided by other Regions, as shown in Figure 3, which reflects the map of transition to the "new normal" after the first wave, available on the Spanish government webpage.

During the first phase of the pandemic, the so-called de-escalation was carried out in most of the country at the provincial level, and decisions were taken on the pace of the process in that territorial unit. In almost all regions, as shown in the map, this was the prevailing model. However, there were some exceptions, such as the Basic Health Areas in Castile and Leon, the Health Zones in Catalonia and the Health Departments in the Region of Valencia. Subsequently, the Region of Madrid also applied the BHA as territorial basis at some points in the de-escalation phases, a process which led to significant problems caused by the obvious difficulty in compartmentalizing the territory at the urban scale.

This contingency has given rise to evident contradictions and dilemmas somehow difficult to understand during the pandemic. In Castile and Leon, a dual type of official cartography has been generated in terms of strategic monitoring data on the disease and the measures adopted to deal with it. On the one hand, the administration has disseminated an analytical and prospective cartography on the delimitation of the BHA as basic health units for the gathering of information, analysis and decision-making. On the other hand, and simultaneously, a cartography on the limits of the provincial and municipal administrative divisions has been produced as a reflection of the management organization in the establishment of restrictive and containment measures. The units of sanitary analysis and the theoretical functional division of the territory are not compatible with the administrative unit that must apply the management measures.

Figure 4. Map of transition to the "new normal"

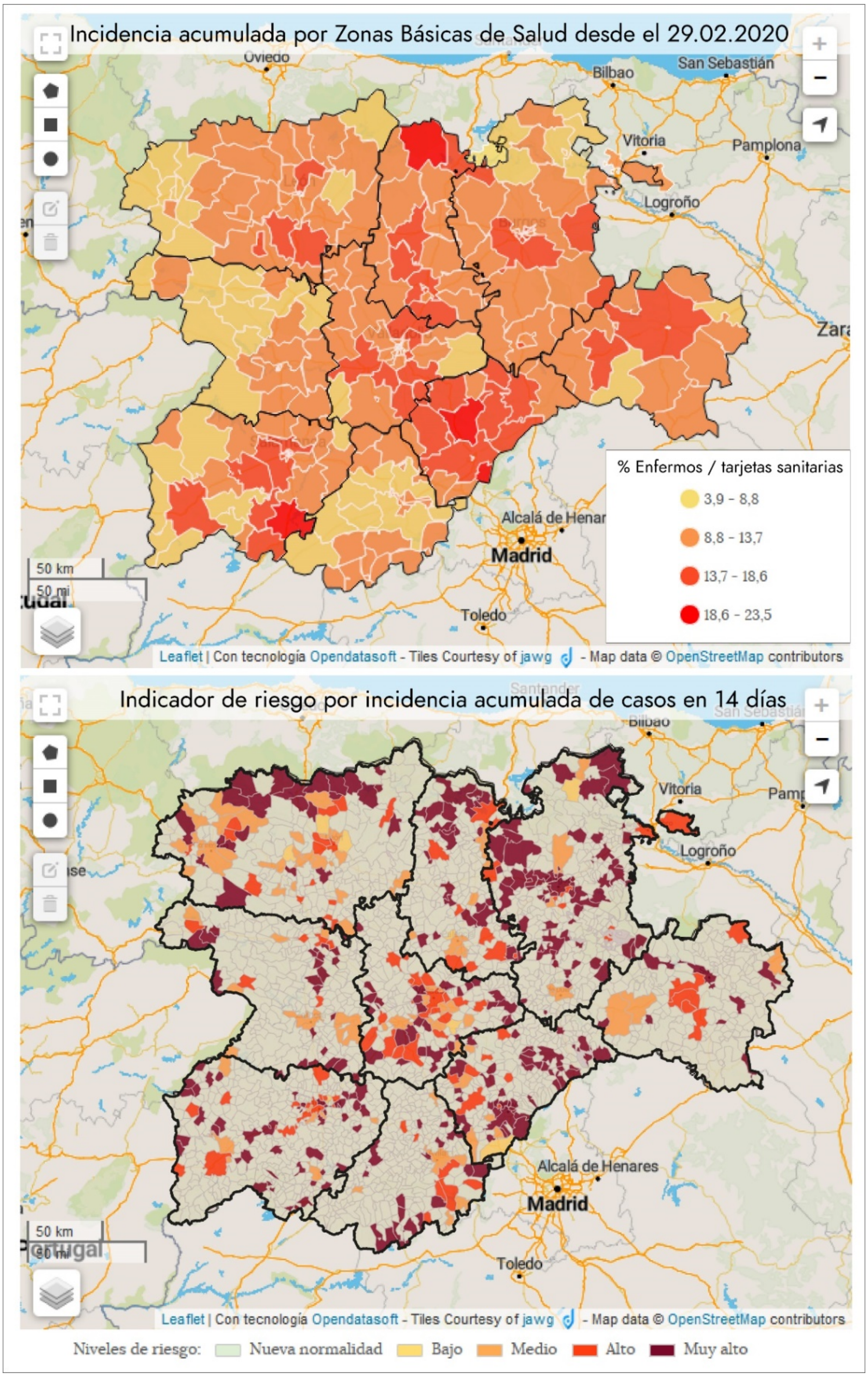
Source: map of transition to the "new normal" (Spanish Government, 2020), available at https://www.lamoncloa.gob.es/covid-19/Paginas/mapa-fases-desescalada.aspx

This conditioning factor has made difficulties become more severe when addressing the cartographic development and generating maps at the appropriate scale with the analysis of the evolution of the pandemic, since the information provided at the level of detail of cases by the Regional Government of Castile and Leon is limited to the scale of BHA, and does not allow to count on detailed information at the municipal level. For reasons of statistical secrecy, detailed case information is only available for 243 of the 2,248 municipalities in the region, those with more than 1,000 inhabitants. For the rest, only relative incidence indicators are provided.

Nevertheless, it is precisely this scale of the municipality that the administration employs to take measures on restrictions of mobility and economic activities as well as lockdowns. The reality is that, in Castile and Leon, we move from the province, as the initial unit of state measures, to the BHA as units of health analysis to determine the situation of health resources and centers in relation to the state of infection. However, we end up intervening in the municipalities as administrative units of management. Thus, the aforementioned dual cartography shown in Figure

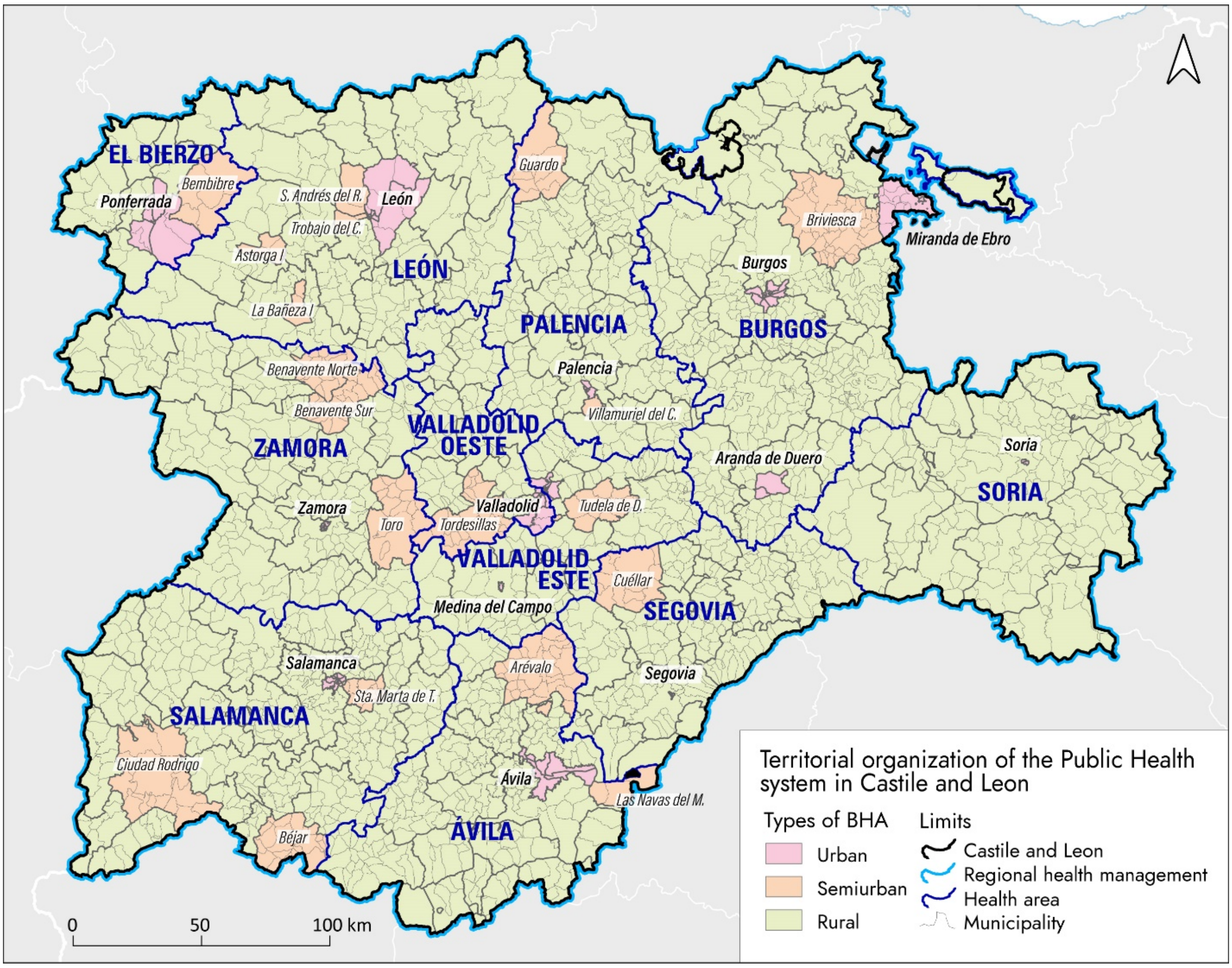
4 is generated both for the sanitary analysis —at the BHA level— and for taking intervention measures —at the municipal level.

Figure 5. Cumulative incidence in BHA (health analysis units) and 14-day cumulative relative indicators by municipality (management units) in Castile and Leon



Source: own elaboration based on Regional Government of Castile and Leon (2020)

Figure 6. Map of the territorial organization
of the public health service of Castile and Leon



Source: own elaboration

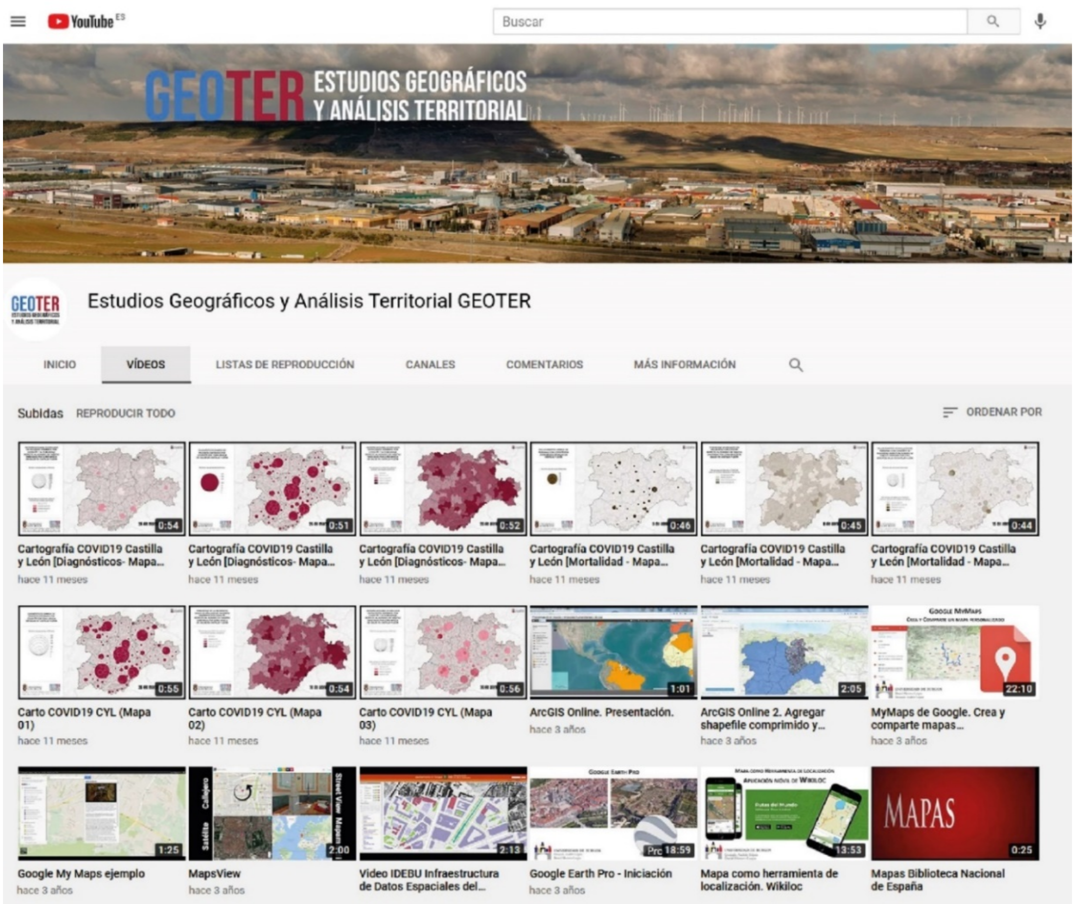
All this has resulted in the two-fold limitation of the cartographic analysis capacity. On the one hand, due to the impossibility of obtaining municipal and submunicipal data (at microdata scale) that would allow the generation of detailed maps without being subject to the administrative delimitation with jurisdiction (the municipality). On the other, because of the incompatibility for the follow-up of the correspondence between the data of these municipal management units and the sanitary analysis units (BHA). Considering this conditioning factor, we have developed the project by using the available information by BHA, which has been organized sequentially (by phases of the pandemic) and spatially (grouping BHA according to their provincial location and their rural, semi-urban or urban characterization). The results of the mapping of this process in the two phases are presented below: dynamic maps of the first wave, and thematic maps for the sequence of the three waves of the last year.

4 COVID-19 cartography in Castile and Leon

4.1 Visualizing the first impact of the virus: data animation on dynamic maps (March-April 2020)

As previously indicated, the first days of the pandemic gave rise to a scenario full of uncertainty which prioritized the rapid analysis of the information to obtain trends and conclusions on the dynamics of the spread of the virus. The main objective was to elaborate maps to visualize the spatial distribution of the infection and to monitor its evolution on a daily basis. As was the case in many other parts of the world, rapid access to digital cartography, statistical processing of data in a GIS and audiovisual processing of this information allowed the production of cartographies aimed at communicating the epidemic situation in almost real time. Given the exceptional nature of COVID-19, the use of dynamic mapping was necessary (Esri, 2020a, 2020c, 2020f; Kent, 2020).

Figure 7. Dynamic map board on the YouTube channel of the GEOTER research group



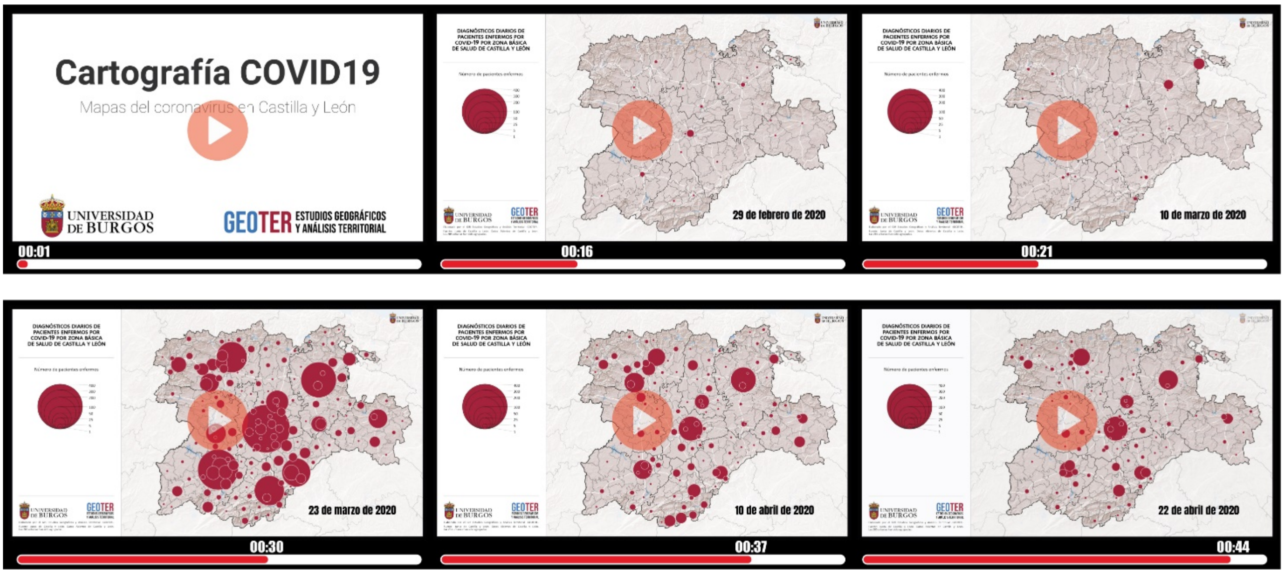
Source: own elaboration, available at https://www.youtube.com/channel/UCzFniyIR6WTnv0jahVnyvPw

The following variables were used to produce these maps using data animation: number of new cases and deaths (persons affected by the virus), percentage of new cases and deaths out of the total number of health insurance cards in each area (rate x 100) and cumulative incidence level of both variables. The data were downloaded daily from the first available date (number of cases as of February 29 and deaths as of March 1, 2020). These data were then employed to create a series of dynamic tables in a database that, in turn, was associated with the spatial unit of correlation of the data (the BHA) in the GIS. Given the regional scale of the map, the urban BHA were grouped and the daily cartographic image of each of the available variables was obtained. Once this daily information was sequenced, the data animation and the creation of the dynamic maps were developed. These were presented in video format and uploaded to the research group's YouTube channel for the entire daily sequence for the months of March and April 2020 (Figure 7).

The final result was the presentation of the following series of dynamic maps for the territory of Castile and Leon, which were daily updated with this time sequence:

- Video with a distribution map of daily diagnoses of COVID-19 patients by BHA in Castile and Leon. Available at https://youtu.be/dvitqwl5SpE
- Video with a distribution map showing the percentage of COVID-19 patients with respect to the number of health insurance cards per BHA in Castile and Leon. Available at https://youtu.be/OjZDS97PNV4
- Video with a distribution map of the cumulative daily incidence of COVID-19 patients and its percentage with regard to the number of health insurance cards per BHA in Castile and Leon. Available at https://youtu.be/OrW2mD0KMz8
- Video with a daily distribution map of COVID-19 deaths (confirmed cases and deceased patients with symptoms compatible with the disease) by BHA in Castile and Leon. Available at https://youtu.be/4G7Zgsi3AzU
- Video with a distribution map showing the percentage of COVID-19 deaths with respect to the number of health insurance cards by BHA in Castile and Leon. Available at https://youtu.be/EK0432qAyKo
- Video with a distribution map of cumulative COVID-19 deaths and their percentage in regard to the number of health insurance cards by BHA in Castile and Leon. Available at https://youtu.be/bKDjWAMCXQI

Figure 8. Sequence of the dynamic map representing the number of people daily diagnosed with COVID-19 by BHA in Castile and Leon



Source: own elaboration

The development of this first dynamic mapping enabled the identification of some of the essential patterns of virus spread during the early phases of the pandemic. The mapping videos illustrated the relationship between the spread of the disease and the main communication corridors in the region, as well as the correlation with the population pattern, identifying the absolute intensity of the phenomenon in the main urban areas (Figure 8).

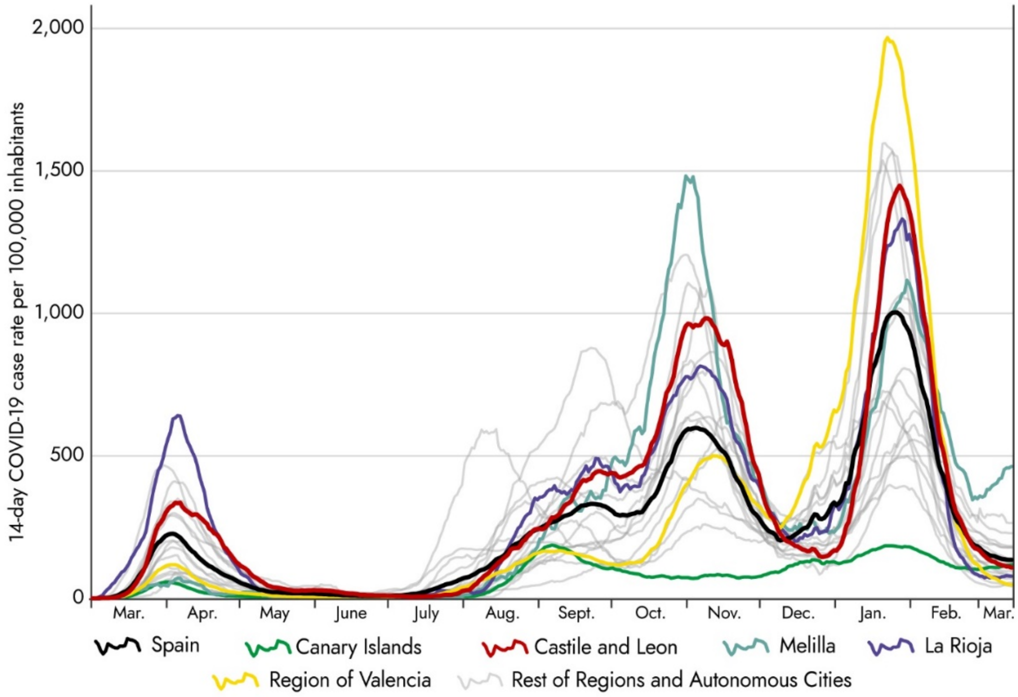
However, the problems of data availability during that first period (due to the lack of diagnostic capacity), the deficiencies in the counting systems (because of the problems of cumulative data and delays in updating them) and the generalized uncertainty about the process added considerable doubts to the validity of the results. The intensity curves shown in the dynamic maps in different territories with similar geographic characterization were not easily explained and, as has been subsequently verified, in many cases responded to the phenomenon of the lack of reliability and consistency of the existing information at the time. On the other hand, this dynamic cartography was an effective and rapid contribution from the University to provide an initial diagnosis, since this possibility of visualization was not available. However, later on, the regional administration began to update its information on its web and started to offer cartographic results that allowed the visualization of the updated data. Besides, the daily sequential elaboration of the data animation to obtain the videos was very costly and required considerable resources for their publication. For this reason, it was decided to undertake a more detailed analysis by means of thematic cartography in a second phase of the project. This second phase began in June 2020, a moment when the available information started to be filtered and tables, graphs and sequences of thematic maps with the different variables related to the spread and distribution of the disease were elaborated. Between June 2020 and March 2021, this information was gathered and tabulated so that the statistical sequence could be followed up to elaborate the results of the mapping on COVID-19 in Castile and Leon during the last year.

4.2 Temporal dynamics and evolutionary sequence of disease spread during the first year (March 2020–March 2021)

In order to identify the dimension of the pandemic in this region and to situate its evolutionary dynamics in comparison with the rest of the country, the contextualization of the maps required a prior analysis of the statistical information available. According to information from March 2021, the Region of Castile and Leon accumulated more than 285,000 detected cases and more than 10,500 deaths due to COVID-19, figures which represent slightly more than 8% of the total number of cases and nearly 14% of the total number of deaths in Spain —demographically, it barely reached 5% of the national total. As shown in tables 1 and 2 and Figures 9 and 10, the figures for the incidence of the number of cases and number of deaths place Castile and Leon in a significantly more intense position in terms of COVID-19 than the average for the rest of the Spanish territories.

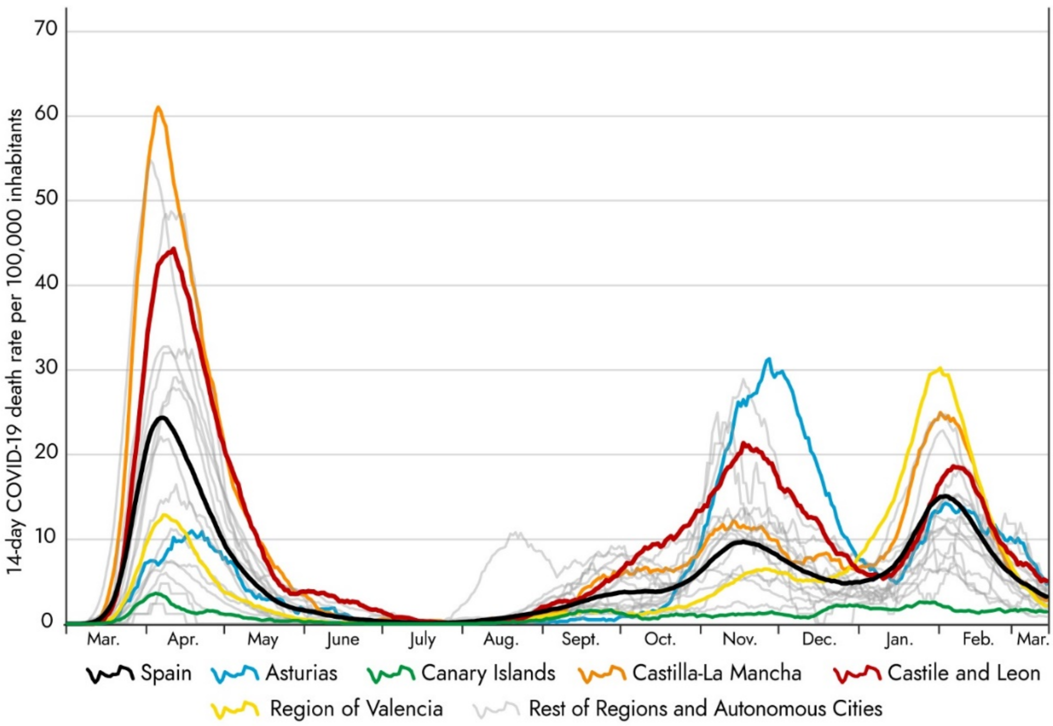
During the first wave, between March and June 2020, Castile and Leon reported more than 300 cases and more than 40 deaths in 14 days per 100,000 inhabitants, figures which clearly exceeded the average and ranked the region as the fourth with the highest incidence of the disease in Spain. In the second wave (June—December 2020), this position was maintained and doubled the national average both in number of cases and deaths (almost 1,000 cases in 14 days per 100,000 inhabitants compared to just over 500 in the country as a whole; and 21 deaths on average in the same 14-day rate compared to 10 deaths at the national level). In the third wave (January to March 2021), Castile and Leon still showed a very high intensity, 50% higher than the national average in number of cases (almost 1,500 versus 1,000 per 100,000 inhabitants in 14 days), with a slight mitigation of the impact of the death ratio.

Figure 9. 14-day case rate per 100,000 inhabitants (1 March 2020—14 March 2021)



Source: own elaboration based on epidemiological data from the CNE and continuous population census as of 1 January 2020 from the Spanish Statistical Office

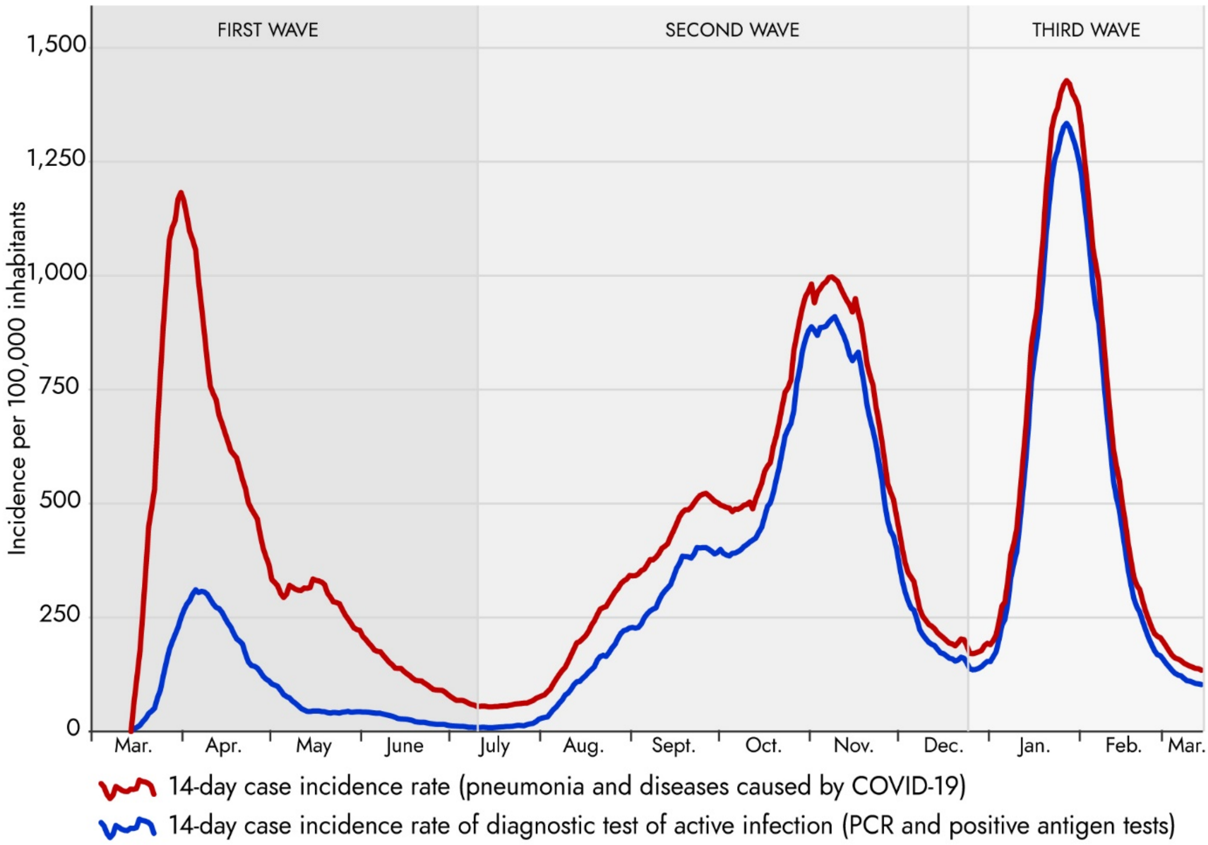
Figure 10. 14-day death rate per 100,000 inhabitants (1 March 2020—14 March 2021)



Source: own elaboration based on epidemiological data from the CNE and continuous population census as of 1 January 2020 from the Spanish Statistical Office

The region only falls below the national average during the valleys of the phases in the three waves, subsequently rising in a similar way to other regions, but showing higher intensity peaks. Particularly noteworthy is the maintenance of a high level of sustained incidence in all phases of increased infection and a strong correlation between high level of infection and high mortality, which is not reached in other territories —only the regions of Aragón and Castilla-La Mancha show similar trends with a continued high impact on both variables. There are other regions where the intensity of the virus has caused the disease to reach higher levels of infection during some of the waves, but its rates have decreased in the following waves or have been altered in each of the phases. Likewise, regions such as La Rioja present sustained high levels of infection over time in all phases, and do not show a high mortality rate as in Castile and Leon. Similarly, the Region of Valencia, which leads the incidence and mortality ratios in cases and mortality in the third wave, does not present this condition in the two first waves; or Asturias, which reached the highest mortality levels during the second wave, but does not maintain such a high ratio in the other two phases.

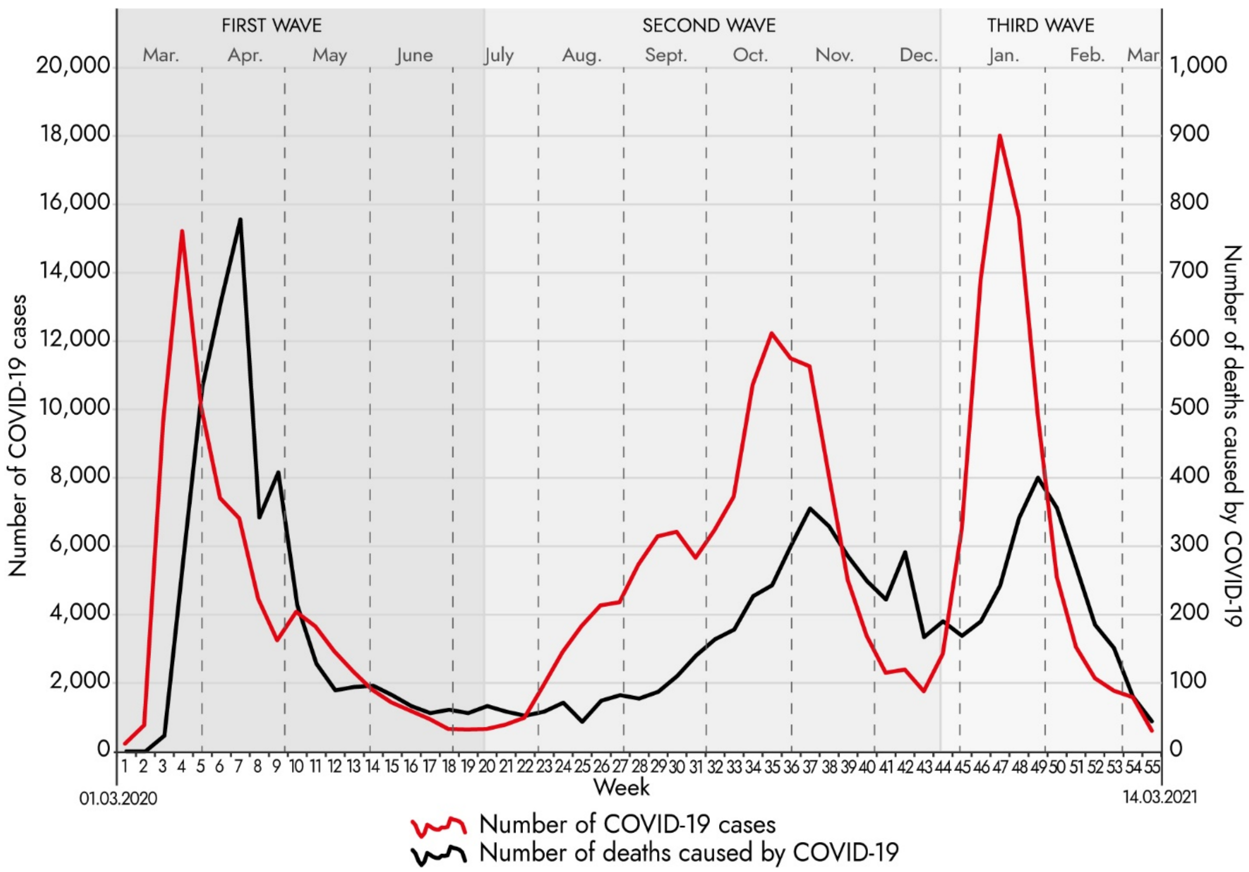
Figure 11. Comparison of the 14-day incidence rate in Castile and Leon



Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

Therefore, it can be deemed that the most defining characteristic of the pandemic in the region is the evidence of its sustained impact over time, showing a high intensity of cases which in turn evidence a worrying degree of correlation with mortality. Castile and Leon hasone of the highest cumulative incidence rates of COVID-19 cases in the country over the last year (11.8 cases per 100 inhabitants compared to 6.76 cases in the national average) and also a very high mortality rate (0.43 deaths per 100 inhabitants compared to 0.16 on average in Spain). In spite of this fact, as in the rest of the Spanish regions, there is a clear decrease in the intensity of the number of deaths among the three waves. While the number of infections is clearly increasing in each of them, the number of deaths is decreasing in accordance with the advances in prevention systems, detection capacity and health methods applied to the disease.

Figure 12. Weekly evolution of the number of COVID-19 patients and deaths in Castile and Leon



Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

In this regard, the relative incidence graphs clearly reflect the manifest increase in the second and third waves with respect to the first. However, we ought to consider that this information does not fully reflect the reality of the impact of the pandemic, since in the first phase the diagnostic capacity was limited and not all the cases actually affected were counted. Figure 10 illustrates the evolution of the 14-day incidence rate of the disease in Castile and Leon in the two statistical variables that compute the phenomenon. On the one hand, persons affected by the disease, i.e., COVID-19 patients (including the infection itself and the pneumonia it may cause). On the other, positive cases detected by PCR and antigen tests. As shown, the degree of coincidence is high in the second and third waves, when the diagnostic capacity was multiplied, and testing was massively extended. However, the number of patients during the first wave in the region is five times higher than those actually detected with tests in that first phase (about 1,200 cases per 100,000 people in 14 days, compared to only 300 cases detected with infection testing methods).

Taking into account this conditioning factor, the real analysis of the pandemic in the region should be carried out with the statistics on the number of patients, considering the incidence of infection in all cases in which COVID-19 causes a health problem. By assessing the actual number of people affected, the relative incidence of the three waves can be compared. Figures 11 and 12 show the number of patients and the number of deaths in each of these phases. During the first wave, 77,770 patients and 3,967 deaths were reported —5.1 deaths per 100 patients. In the second wave, 126,446 patients and 3,929 deaths —3.1 deaths per 100 patients. Finally, in the third wave, 80,895 patients and 2600 deaths —3.2 deaths per 100 patients.

As shown, the impact of the initial mortality is restrained in the following waves, stabilizing as the sanitary measures against the virus progress. The sequence that interrelates the number of patients and deaths per week becomes more and more separated as the months go by. While the curve of illnesses and deaths is practically symmetrical during the first wave, in the second and third waves the effect of mortality decreases considerably.

On the other hand, the duration of the waves should be taken into account, considering the dates of maximum and minimum daily infection level. While the first wave lasts 133 days (February 29 to July 10, 2020), the second spans 168 days (July 11 to December 25, 2020) and the third wave 79 days (December 26, 2020 to March 14, 2021). This means rates for Castile and Leon of 30 deaths/day in the first wave, 23 deaths/day in the second wave and 33 deaths/day in the third wave. The graphs evidence how the intensity of the increase in cases and deaths is higher in the first and third waves, which concentrate a space of a "peak" rise and fall for 8-10 weeks; while, during the second wave, in the summer, the spread increase is more gradual and the time span from the beginning to the return of the peak to low levels is prolonged by 20 weeks.

Table 1. Number of COVID-19 cases by health area and month in Castile and Leon during the first three waves (1 March 2020—14 March 2021)

	2020										2021			Overall total	Cumulative case rate per 100 inhabitants
Health Area	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March		
Ávila	2,413	2,136	939	376	182	877	1,311	1,784	1,400	491	3,697	728	55	16,392	10.02
El Bierzo	950	871	407	235	167	307	630	1,823	1,554	558	2,416	468	63	10,450	7.82
Burgos	4,755	3,739	1,790	598	550	3,155	3,875	7,195	8,324	2,205	4,377	2,174	802	43,551	12.03
León	4,204	3,371	1,410	816	311	1,101	3,254	5,713	4,781	1,279	7,809	3,724	612	38,390	12.07
Palencia	1,598	1,547	738	388	213	792	1,705	3,012	2,570	1,356	5,732	2,006	223	21,886	13.83
Salamanca	5,765	3,954	2,058	734	393	2,549	3,821	6,616	3,607	1,122	9,089	2,637	517	42,883	12.70
Segovia	3,624	2,564	1,778	680	463	1,148	1,770	1,887	1,613	1,083	5,969	1,589	358	24,538	15.70
Soria	1,690	1,588	931	338	295	762	697	852	1,238	325	1753	1,150	270	11,895	12.60
Valladolid East	2,876	2,723	1,052	651	451	1,652	3,615	4,421	4,376	1,089	6,545	1,868	366	31,698	12.07
Valladolid West	2,574	2,627	1,150	546	254	1,463	2,547	4,451	4,087	975	6,286	1,403	270	28,646	10.83
Zamora	1,134	1,134	1,058	195	73	477	1,517	2,432	2,687	655	3,076	616	77	15,140	9.04
Regional Health Management total	31,583	26,254	13,311	5,557	3,352	14,283	24,742	40,186	36,237	11,138	56,749	18,363	3,613	285,469	11.80
Total Spain	124,242	101,622	19,772	10,321	46,868	192,885	316,179	475,123	402,728	297,235	860,945	290,044	63,872	3,201,836	6.76

Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

Table 2. Number of COVID-19 deaths by health area and month in Castile and Leon during the first three waves (1 March 2020—14 March 2021)

	2020										2021			Overall total	Cumulative death rate per 100 inhabitants
Health Area	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March		
Ávila	64	188	49	25	29	33	38	42	61	34	56	73	17	709	0.43
El Bierzo	12	71	18	13	11	8	12	37	61	50	46	49	8	396	0.30
Burgos	56	259	71	41	26	25	72	96	228	197	124	91	27	1,313	0.36
León	111	321	84	43	40	33	48	191	209	157	165	215	34	1,651	0.52
Palencia	19	98	19	15	12	12	26	62	100	118	132	110	28	751	0.47
Salamanca	105	444	125	42	44	55	71	129	159	99	141	202	24	1,640	0.49
Segovia	109	357	43	41	37	29	22	40	50	43	103	73	4	951	0.61
Soria	52	160	36	24	13	19	17	26	49	46	48	78	24	592	0.63
Valladolid East	37	219	29	17	20	24	45	77	94	92	98	99	33	884	0.34
Valladolid West	50	184	49	28	26	21	37	99	183	66	81	90	13	927	0.35
Zamora	9	92	32	15	9	16	37	84	143	110	70	70	13	700	0.42
Regional Health Management total	624	2,393	555	304	267	275	425	883	1,337	1,012	1,064	1,150	225	10,514	0.43
Total Spain	10,388	15,733	3,037	589	167	1,060	3,175	5,139	9,035	5,600	11,318	8,403	1,522	75,166	0.16

Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

Likewise, different intensities were observed in each wave in the different provinces of the region, thus showing different spatial behaviors of virus infection (Tables 1 and 2). All these dynamics observed in the evolutionary sequence of the spread of the disease during its first year in Castile and Leon display multiple contrasts that can be identified through a more detailed cartographic analysis of the information. The maps suggest some differences in the territory and show graphically its spatial impact in the region.

4.3 Spatial analysis and thematic mapping: contrasts and trends in COVID-19 maps in Castile and Leon

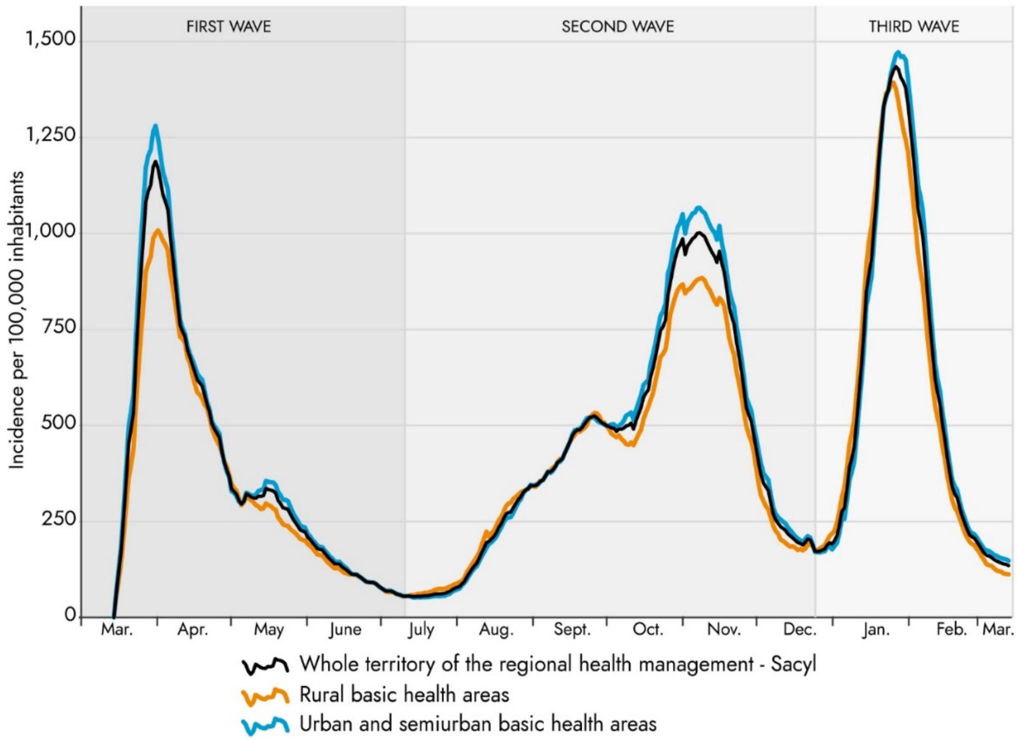
From a territorial perspective, there are conditioning factors related to the demographic characteristics of the disease and the population model in Castile and Leon. The study carried out by the CNE on factors in the spread of COVID-19 in Spain elucidates that the highest effect on the spread of the disease in Castile and Leon is related to the high number of nursing home places per 100 people over 70, with a moderate effect of the percentage of infected health personnel, as well as the infectious risk of internal mobility (low) and external mobility (moderate-low in Madrid and very low in the Basque Country). The selective incidence of the pandemic in the region presents a certain relationship with the aforementioned aging sociodemographic structure as well as with an extensive territory with a population model concentrated in the cities and a vast and severely depopulated area (CNE, 2020). However, this initial diagnosis, which suggests a differential pattern between urban and rural spaces, requires some clarification.

Firstly, the classic epidemic models of expansive contagion by proximity must be considered, those explained from the generalization of global mobility. Cities have historically been associated with the spread of infectious diseases, and recent studies on 21st century pandemics have confirmed the effect of urban density on the ease of spread. It has been shown that while sparsely populated areas with few air connections and poorly developed traffic networks tend to be less affected in more connected and dense territories —mainly large urban agglomerations—, the spread tends to be higher, faster and more intense in territories that are more connected (Cos de, Castillo & Cantarero, 2020a; Méndez, 2020; Valjarević et al., 2020).

Scholarship has proven that population density especially affects the timing of outbreaks, since greater connectivity in a denser territory impairs control of spread. However, it is important to distinguish the differences between the initial spread, at the time of the onset of the infection, and the subsequent spread, once the transmission phase has started; as well as to discern the dynamics among cities and within them, which particularly affects the rural-urban dichotomy of Castile and Leon. In rural areas, the dynamics of contagion and the onset of transmission may take longer to take place, but when the virus has taken effect, the expansive dynamics usually reach the same or greater intensity of contagion, relatively speaking. In urban centers, at the neighborhood level, the socioeconomic profile is more decisive than the density itself in understanding the distribution relationship of COVID-19. Knowledge of the spatial behavior of COVID-19 therefore requires a multiscale analysis (Carozzi, Provenzano & Roth, 2020; Orea & Álvarez, 2020; Páez et al., 2021; Oto-Peralías, 2020).

The studies relying on urban micro-scale data conclude that neighborhoods with poorer living conditions, higher unemployment rates, lower qualifications and training of their population, lack of internet access, lower income levels or high levels of aging have a direct correlation with a higher disease affection and the impact of virus transmission during an epidemic situation. In each neighborhood, depending on income levels, housing typology and other socioeconomic aspects, the effects of COVID-19 are experienced differently. One pattern prevails universally: COVID-19 knows about class. Pandemic maps show the unequal cities (Bilal, 2020; González & Piñeira, 2020; Méndez, 2020).

Figure 13. Evolution of the 14-day incidence rate of COVID-19 patients by type of BHA



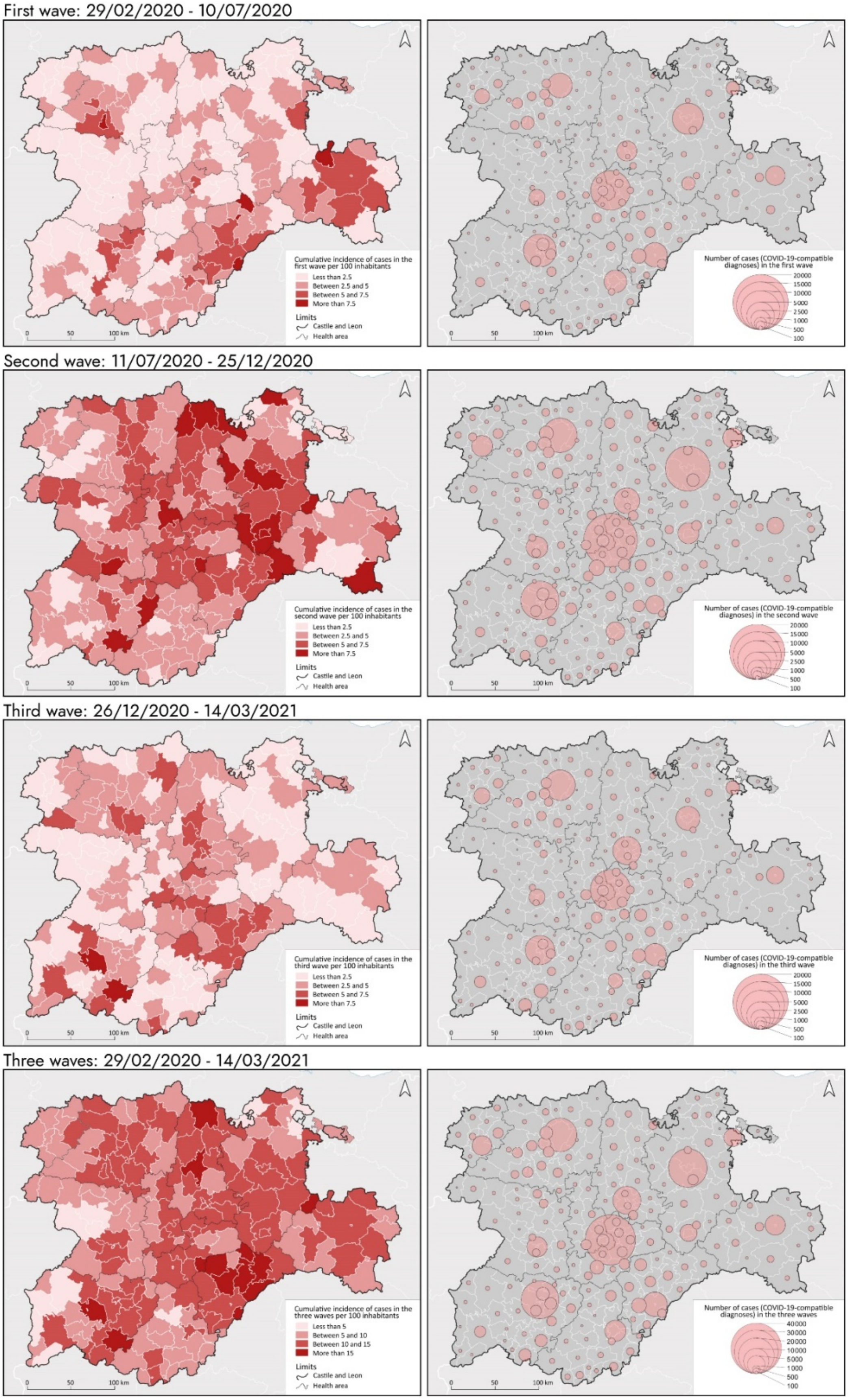
Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

However, apart from the scale of the microdata —which is not available in Castile and Leon—, it should be pointed out that the dichotomy that suggests a differential impact of the pandemic between rural areas and cities is not as evident as might be expected considering the general indicators. If we look at the basic evolution of the 14-day incidence rate by BHA (Figure 13), we can see how, in general, rural areas have a more moderate incidence of the virus than cities, which accumulate higher relative peaks of intensity during the phases of greatest contagion. Rural areas only exceed the average level of infection during the phases of lower intensity peaks and they do so very occasionally. Nevertheless, this first diagnosis requires consideration of the representation offered by the maps on two grounds. On the one hand, because the general figure for rural areas includes a complex diversity of scales in municipalities with very different demographic and socioeconomic conditions; and, on the other, because the general infection figures (total number of cases) must be studied with a different approach with respect to the relative level of incidence on the population of each territory. The maps in Figures 14 and 15 certainly reveal the differential condition between rural and urban areas by considering both perspectives (absolute and relative).

The maps showing the total volume of patients are a clear image of the urban system of the region, since the largest number of cases is in the cities, where the bulk of the population is grouped. In the cumulative rate of the three waves, the cities show the worst absolute values: Valladolid, Burgos, Salamanca, León and Palencia —the five largest urban areas— add up to 116,135 cases, more than 40% of the total in the region. In fact, the twelve largest cities in the region account for 57%, with more than 161,000 cumulative cases. If we look at the number of deaths, the result is similar, although it is somewhat more nuanced, as the impact of urban areas decreases. The five major capitals account for 3,166 of the 10,514 deaths, and the cities as a whole for 44% of the deaths. The strongest impact of the pandemic is in the cities in absolute terms, but the number of deaths plays down the urban-rural dichotomy, since mortality is not so marked in urban areas, where the ageing rate is lower than in rural areas.

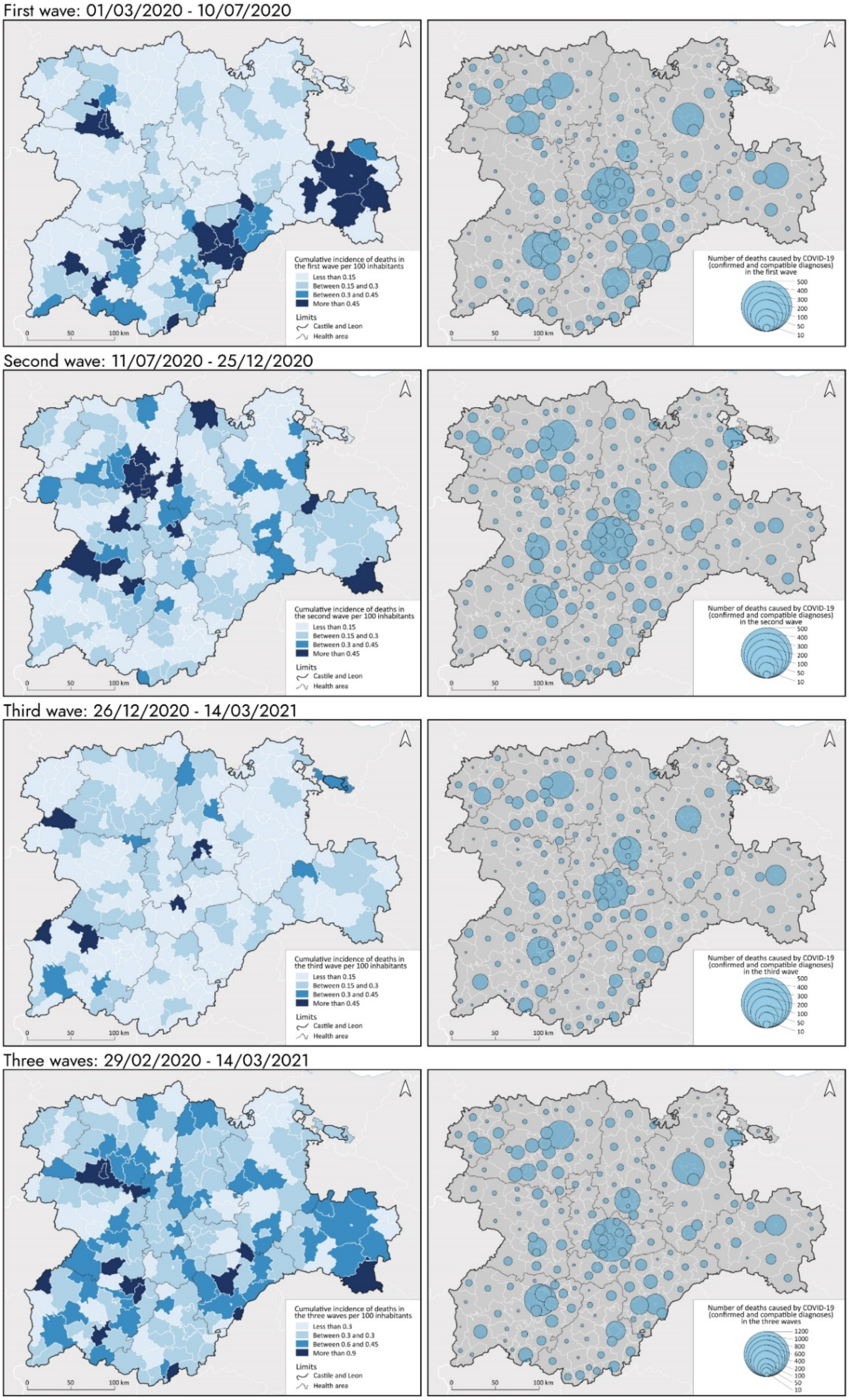
In this sense, the spatial distribution structure is presented in the maps showing the relative incidence levels: the highest percentage infection rates are found outside the cities. Some rural BHAs in Segovia, Soria, Palencia or Salamanca concentrate ratios higher than 15 cases per 100 inhabitants. Likewise, the number of deaths accumulated over the total population of each area reflects the relative intensity of the virus in rural areas. There are nine BHAs in Castile and Leon with a rate of more than one death per 100 inhabitants, a pattern not repeated in any of the cities and that reveals the aforementioned correlation between the degree of rural aging and the intensity of the severity of the virus in this type of area. Additionally, the maps indicate that several rural BHAs restrain the disease in the first or second wave and report hardly any cases and thus remaining somehow isolated from the disease (Valle de Sedano and Valle de Losa, in Burgos; Alta Sanabria, in Zamora; Carbajales de Alba, in Salamanca). However, when the disease is finally detected in these areas, the levels of the intensity of the infection soar and reach incidence rates similar to those of the rest of the areas.

Figure 14. Case incidence rate per 100 inhabitants and number of patients per BHA in each wave and in total



Source: own elaboration based on the Regional Government of Castile and Leon (2020–2021)

Figure 15. Death incidence rate per 100 inhabitants and number of patients per BHA in each wave and in total



Source: own elaboration based on the Regional Government of Castile and Leon (2020—2021)

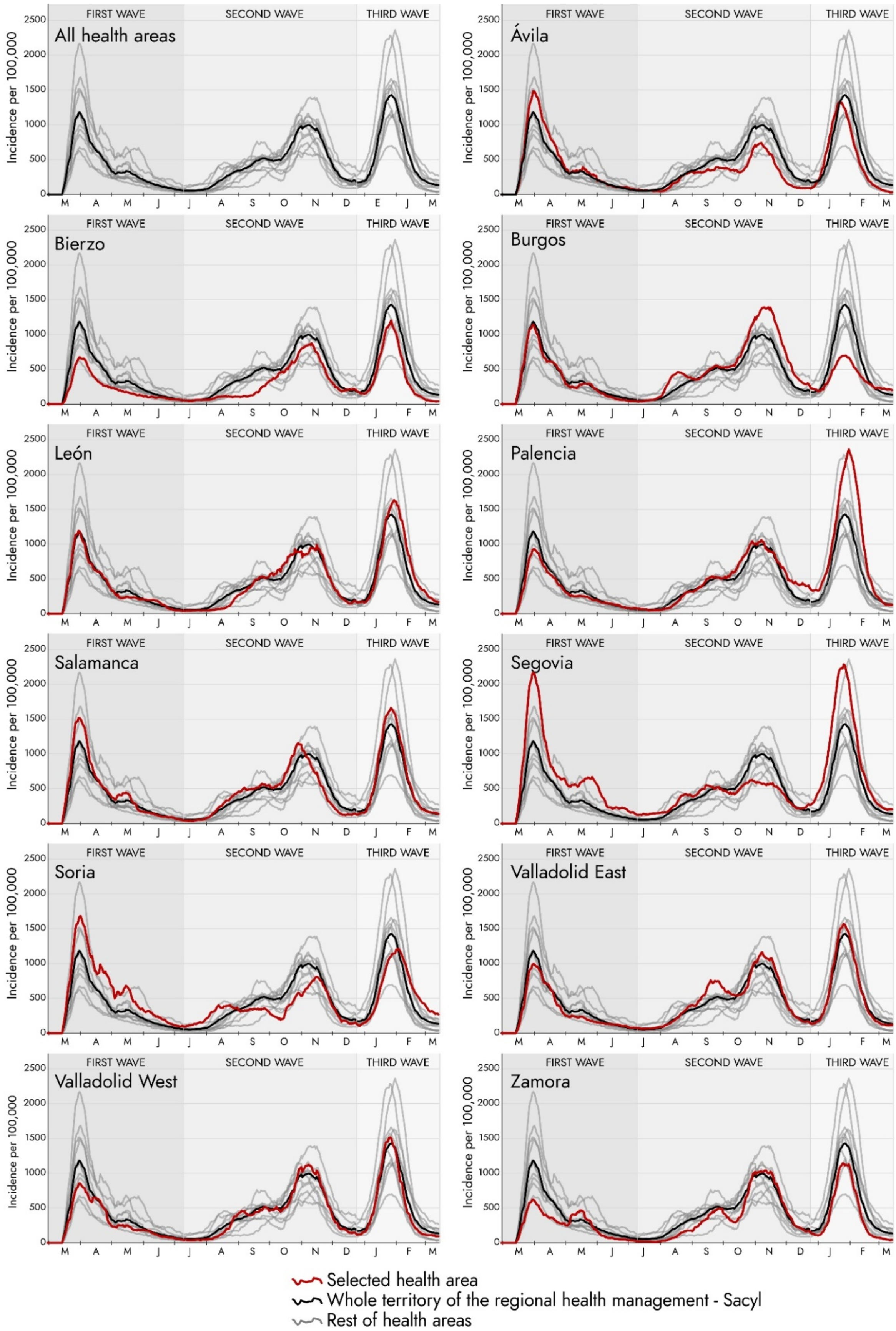
Furthermore, the maps show the differential evolution of the three waves over the last year. The level of intensity of the second phase of the viral infection between July and December 2020 can be clearly seen, compared to the lower intensity of the first and third waves. It is also possible to identify the areas most affected by the intensity of the process during each phase.

In the first wave, the number of cases and deaths was mainly concentrated in the cities of Valladolid, Burgos and Salamanca, on the axis that crosses the region diagonally (France—Portugal connection), where one out of every three cases reported occurred. However, the main BHAs in terms of relative intensity of infection were located in the southeast quadrant of the Region, in the provinces of Segovia and Soria. These same BHAs, and some others in the provinces of León and Salamanca, had the highest mortality rates.

During the second wave, the most relevant volume of cases continued to be reported in the three provincial capitals abovementioned, to which the increase in the cities of León and Palencia was added —these five cities accounted for almost one out of every two cases at that time of the pandemic. Relatively speaking, the infection especially affected a group of BHAs located in the center of the Duero basin, with special incidence in the southern part of the province of Burgos and some areas of Valladolid, Palencia and Soria. In this second phase, two aspects are worth highlighting: on the one hand, the relative mortality did not stand out in these areas of greater absolute volume, but was mainly concentrated in the rural BHAs of León, Zamora and Salamanca,; and, on the other, the high volume of infection also meant that the relative incidence of some urban BHAs (Burgos, Valladolid, Aranda de Duero…) rose remarkably.

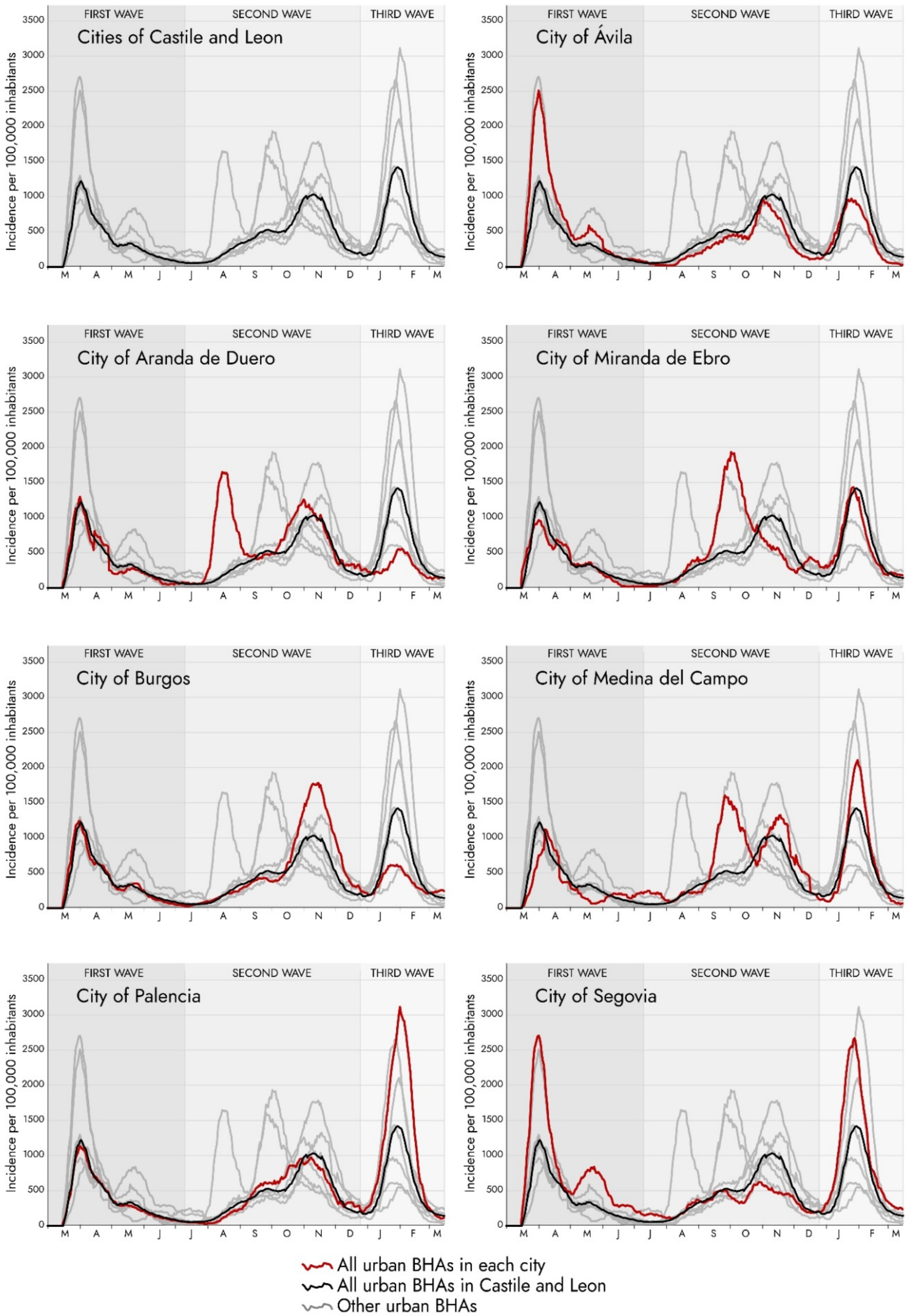
In the third wave different behaviors arose, and the distribution of the virus modified the patterns described above. At the absolute level, the highest infection rates were again concentrated in cities, especially in Valladolid, Palencia and León, while Burgos and Salamanca showed a certain containment. Relatively speaking, the BHAs of the provinces of Soria and Burgos, which were very affected in the previous waves, also showed more reduced levels of contagion, probably due to some of the selective measures of perimeter closures and selective closures of activities in these territories during the second wave. In contrast, the axis made up by Segovia, Valladolid, Palencia, and León, in the central quadrant of the region, showed the highest relative incidence rates. The relative number of deaths fell across the board and, although it stood out in some BHAs of this central axis, it also showed high rates in other areas scattered throughout the territory (León, Salamanca, Burgos or Soria).

Figure 16. Evolution of the 14-day incidence rate of patients by health area



Source: own elaboration based on the Regional Government of Castile and Leon (2020–2021)

Figure 17. Evolution of the 14-day incidence rate in the cities with the most dissimilar data with respect to the average for the cities of Castile and Leon



Source: own elaboration based on the Regional Government of Castile and Leon (2020–2021)

All these spatial trends in the distribution of the infection and the level of incidence of the disease during the three waves of the last year can also be observed in the Figure 16 and 17, which represent the differential dynamics of each basic health area of a representative group of cities respectively.

These graphs ratify the trends shown in the cartography: the highest incidence in Soria, Segovia or Salamanca during the first wave; the intensity of COVID-19 during the second wave in Burgos; or the strong concentration of the disease in the axis of Segovia, Valladolid, Palencia in the third wave. Likewise, urban dynamics confirm these trends and also illustrate some specific cases that visualize the singular intensity and anticipation of the second wave in cities such as Burgos or Aranda de Duero and Medina del Campo, where there is a double peak of incidence in this phase. However, the regional-scale study presented here, based on the systematic processing of the official information available and its cartographic representation, reveals the difficulty of understanding the phenomenon, given the impossibility of establishing clear patterns of contagion and predictable patterns of spatial evolution of a disease about which much remains to be known.

5 Conclusions

The COVID-19 cartographies in the Spanish region of Castile and Leon verify the use of maps as useful tools for the analysis of the spatial distribution, the dynamics of infection and the differential impact of the pandemic in the territory. On the one hand, the mapping of the dynamics of infection, as a means of geographical analysis from the University, has been useful to improve the visualization of the spatial distribution of the foci of infection during the first wave through the creation of dynamic maps. This initial study with sequences of data animation allowed to contextualize the position of the region within the framework of the country. The data analyzed placed Castile and Leon as one of the most affected in Spain in terms of volume and relative intensity of infection and mortality. The statistics handled in the mapping clearly showed the high impact caused by COVID-19 in the region, which doubles the national average of patients per 100 inhabitants (12 cases *versus* 6) and triples the number of deaths (0.43 versus 0.16 per 100 inhabitants).

However, beyond the intensity diagnosis, the analytical use of maps offers a detailed representation that unravels the differential behavior of the virus and shows its temporal and spatial sequences. Mapping identifies contrasts in the impact of the disease. On the one hand, the maps confirm the imbalance in each of the waves of infection, highlighting the greater intensity of the second, and the more concentrated effect in time of the first and the third. On the other hand, they reveal the discrepancies of the pandemic in the different territories of the region and enable to identify more clearly the dichotomies between urban and rural areas in the face of the impact of COVID-19. The former have a higher absolute incidence and the latter present high levels of relative incidence, once the disease is detected in them. The greatest number of patients in absolute terms is found in the cities: the map of those affected by COVID-19 in Castile and Leon reproduces the urban system. Valladolid, Burgos, León, Salamanca and Palencia, the five main provincial capitals, account for the largest number of cases. Almost six out of every ten COVID-19 patients in Castile and Leon are registered in the cities. However, this conclusion should be clarified, since the relative incidence of the virus is higher, and its effects are more serious in rural areas. The percentage of sick people in relation to the number of inhabitants is more intense and generalized in all rural areas of the nine provinces, which also report higher mortality rated than the cities. Thus, in contrast to the number of cases, in terms of deaths, the rural environment accounts for six out of every ten deaths; which means that relative mortality is more intense in the countryside than in the city.

Likewise, the maps reveal differential patterns among the cities and the rural areas. In certain urban areas, trends of high incidence are marked during the different waves, during the peaks of infection that divide the sequence of infection (double peaks) in some of the waves. Furthermore, we observe high levels of infection in rural areas which had been very hardly affected in the previous phases. These dynamics visualized by the mapping spark a debate on the problems of interpreting the spatial behavior of the virus and at the same time demonstrate the need for an adequate scale of interpretation.

The study based on information at the intermediate level of the BHAs has not allowed to interrelate these trends with specific socioeconomic factors at the appropriate scale. The mismatches detected between the use of basic health analysis units —as functional divisions— and municipalities —as the essential scale of administrative management of the pandemic— are transferred to cartographic representations and highlight the problems in determining specific patterns in the dynamics of contagion that are useful for decision-making. The contribution of this study on the spatial distribution of infections and the dynamics of the evolution of COVID-19 in Castile and Leon can be improved and expanded if the geolocalized database of each of the cases detected is available. The anonymized processing of this information is compatible with its introduction into a GIS and its spatial analysis could be cross-checked with other socioeconomic information. In a third phase of the project, this process would lead to a study at microdata scale that could complete the initial conclusions presented in this paper.

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