Key Challenges in Geography
EUROGEO Book Series

Aikaterini Klonari
Maria Luisa De Lázaro y Torres
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Re-visioning Geography

Supporting the SDGs in the post-COVID era

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Key Challenges in Geography

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ISSN 2522-8420 ISSN 2522-8439 (electronic)
Key Challenges in Geography
ISBN 978-3-031-40746-8 ISBN 978-3-031-40747-5 (eBook)
https://doi.org/10.1007/978-3-031-40747-5

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Development of a Synthetic Index of Social Vulnerability to COVID-19 in the City of Zaragoza (Spain)

Julia de las Obras-Loscertales Sampériz, María Zúñiga Antón, Marcos Rodrigues Mimbrero, and Carmen Bentué Martínez

Abstract The impacts of COVID-19 are not uniformly distributed, but are closely related to the vulnerability of any given society. This study characterises social vulnerability to COVID-19 in the city of Zaragoza; in other words, the predisposition of certain groups to suffer greater impacts. A new vulnerability index (COVID-19 SVI) was created for this purpose, and its factors (population density, age, female population, foreign population, overcrowding, education level and income level) were weighted by the analytic hierarchy process (AHP) technique through a survey of 404 people from different professional profiles (health care, geography, social work and others). The most valued factors were population density, overcrowding and age, with no differences in criteria by professional profile. By mapping the results at different scales (district, basic health area, census section and block), spatial distribution patterns were identified and the suitability of the scales for analysis compared, revealing the census section as the best option. The use of COVID-19 SVI in social and public health policies can provide essential support to management and decision-making adapted to different situations in the short, medium and long term.

Keywords Geography · Social vulnerability · Decision-making · Public health · Socioeconomic characteristics · Cartography

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A. Klonari et al. (eds.), *Re-visioning Geography*, Key Challenges in Geography,
https://doi.org/10.1007/978-3-031-40747-5_12

Introduction

The World Health Organisation (WHO) declared COVID-19 a pandemic on 11 March 2020. The spread of the new SARS-CoV-2 has been labelled the worst humanitarian crisis since World War II and the greatest health crisis since the twentieth century. Institutions such as the International Federation of Red Cross and Red Crescent Societies classified the pandemic as a natural disaster. As in any disaster, the effects of COVID-19 are not uniformly distributed, but have been closely related to the unequal level of vulnerability associated with welfare and development levels (Barrera et al. 2021; Seddighi 2020; Vincent 2004).

Since the outbreak of the pandemic, several studies have examined the relationship between vulnerability and COVID-19, with prominent ones focused on exposure. For instance, some works in the USA analyse the correlation at different scales between high vulnerability—measured through the Social Vulnerability Index (SVI)—and great likelihood of becoming an infection hotspot (Dasgupta et al. 2020; Karaye and Horney 2020); between high vulnerability and a high ratio of hospitalisation and mortality (Gaynor and Wilson 2020); or between higher vulnerability and a lower number of PCR tests, but a higher fraction of positive results (Borjas 2020). Similar studies conducted in Europe have established the relationship between variables such as age, wealth and ethnic origin and pandemic-induced mortality (Harris 2020).

This work takes a new approach to the study of vulnerability, viewing certain groups as predisposed to suffer greater effects due to socioeconomic factors, which are known as the Social Determinants of Health (SDHs) (World Health Organization 2003). This approach, linked to COVID-19, has not yet been fleshed out. However, some authors have already stressed the important role that SDHs and socioeconomic factors will play in intensifying the effects of the current pandemic.

Socioeconomic and urban spatial inequalities suggest that the pandemic's social impacts will differ according to intersectoral contrasts in variables such as overcrowding, age and income. As such, characterising, estimating and mapping vulnerability can provide essential support for management and decision-making, while laying the ground for improving future social, economic, housing and health conditions.

The main objective of this article is therefore to develop a new index of social vulnerability to COVID-19 (COVID-19 SVI) in the city of Zaragoza to characterise spatial distribution patterns, delving into the possible underlying causes and identifying the factors that experts from different fields consider the most significant in producing social vulnerability.

Methodology

This study was conducted in Zaragoza, the fifth-most populous city in Spain. Since its population of 681,877 is older than the national average, with an ageing ratio of 140.97% versus 125.75% (Instituto Nacional de Estadística), it has particular features that make it interesting to study, such as the coexistence of different urban and residential typologies. Zaragoza is characterised by an urban morphology that includes: (i) a historical centre with narrow and winding streets; (ii) working-class neighbourhoods with high population densities related to urban growth in the 1960s and 1970s; and (iii) suburbs with low population densities linked to the growing sprawl of recent years. This study will perform a multi-scale analysis at four different scales (Fig. 1):

District: territorial divisions with their own administrative bodies. Zaragoza is divided into 15 districts.

Basic health area (BHA): defined as the basic geographical and population framework of Primary Health Care, which may or may not coincide with other territorial demarcations (Fig. 1). There are 33 BHAs in Zaragoza and each has its own Health Council.

Census section: defined as a statistical partition consisting of population of between 500 and 2,000 inhabitants (Ley Orgánica 5/1985). Zaragoza has 491 sections, yet these demarcations vary over time (Villarín Clavería and Segura Calero 2015).

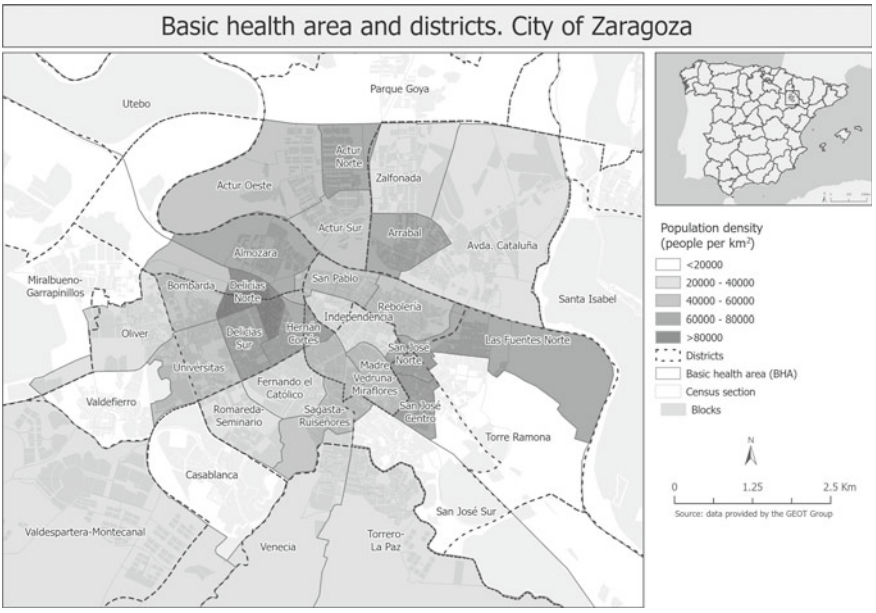

Fig. 1 Case study: City of Zaragoza

Block: defined as "the distance along a street between two intersections" (Cambridge Dictionary). Zaragoza has 2,815 inhabited blocks.

Since the outbreak of the pandemic, Zaragoza has had to deal with several waves of COVID-19 with different characteristics. As of 11 November 2022, the figures were 463,913 confirmed cases and 5,185 deaths (Gobierno de Aragón 2021).

Vulnerability Variables and Factors

Following a review of the literature, seven sociodemographic variables belonging to four dimensions were selected to construct the proposed vulnerability index (Table 1 and Fig. 2):

Urban space configuration: The layout of urban space can significantly influence the transmission of the disease (Sigler et al. 2021) and plays an essential role in producing stress, which has consequences on health (Dorantes Rodríguez 2002). The selected variable—population density per built-up area—was calculated by adding the surface area (in km^2) of the inhabited blocks for each scale of analysis and dividing the result by the total population in 2020. The aim of this operation was to overcome the limitations arising from the size of the demarcations (Escolano-Utrilla 2002).

Demography and population: The WHO considers the pandemic a geriatric emergency owing to the high death rates, the difficultly in diagnosing the disease (Pinazo-Hernandis 2020) and the clinical complexity (Boccardi et al. 2020), which makes it one of the major causes of death. Other related problems include the deterioration of psychological and emotional health, solitude and dependence (Alguacil Gómez et al. 2013). The WHO also considers the female population vulnerable due to the role of women in society (World Health Organization 2021); they are overrepresented in health care, hospitality and cleaning services, face greater economic dependence and less stable employment and shoulder more of the burden in household tasks. Finally, the foreign population was chosen, as foreigners may have problems in accessing the public health services (Gobierno de España 2020), a worse initial health status (Bambra et al. 2020) or impediments such as lack of access to information due to language issues or unstable employment (Liem et al. 2020).

Liveability: This is essential for complying with key policies such as isolation, quarantine and proper ventilation. Its relevant role in psychological development (Gobierno de España 2020) and in daily life (Alguacil Gómez et al. 2013) makes it fundamental in the study of vulnerability.

Socioeconomic status: This is closely linked to unstable employment, unemployment and social exclusion, which are all considered SDH (World Health Organization, 2021). Other related factors include access to information and technology (Cutter et al. 2003).

Table 1 Summary of selected variables

Dimension	Factor	Variable	Interpretation	Source
Urban space configuration	Population density	Population density per built-up area (inhabitants/km^2)	Higher density, higher vulnerability	Municipal Register February 2020
Demography and population	Age	Percentage of population over 60	Higher percentage of population over 60, higher vulnerability	Municipal Register February 2020
	Female population	Percentage of female population	Percentage of female population, higher vulnerability	Municipal Register February 2020
	Foreign population	Percentage of foreign population	Percentage of foreign population, higher vulnerability	Municipal Register February 2020
Liveability	Overcrowding	Percentage of people living with five or more people in less than 90 m^2	More people, higher vulnerability (higher overcrowding, higher vulnerability)	Cadastre February 2020
Socioeconomic status	Education level	Percentage of population that is illiterate or without primary education	Lower education level, higher vulnerability (higher percentage, higher vulnerability)	Municipal Register February 2020
	Income level	Per capita income (€)	Lower income level, higher vulnerability	National Statistics Institute (INE, acronym in Spanish), June 2017

Construction and Calculation of the Social Vulnerability Index

Applying weights to indexed variables is both essential and complex, and as all techniques have advantages and disadvantages. To avoid the dependence of statistical techniques, such as the principal components (Spielman et al. 2020), weights were obtained through a participatory process in which experts belonging to different fields

Fig. 2 Summary of selected variables. Diagram of how the selected variables interact with and influence social vulnerability. Created by the authors

(health care, social work and geography) and different sectors of the population took part in a survey. The survey was disseminated through different media and social networks both to specific research groups and to the general public. Although at first it was thought to be a random spatial sampling, in the end it was mainly focused on inhabitants and researchers of the city under study, Zaragoza.

The survey and methodology used to obtain weights were based on the analytic hierarchy process (AHP) technique, used and contrasted in many fields and applications. To get the weights, this method is based on conducting a pairwise comparison of the importance of each variable (Saaty 2008), in this case as vulnerability factors. A survey was executed for this purpose. The first section asked the respondents for general data that would later be needed for profile analysis (occupation, age or birthplace). The second section compared the factors. There were 21 questions in total in random order, so as not to put the last answers at a disadvantage. For each question, the survey respondent had to assess the relative importance of one variable compared to another on an ordinal scale: "very strong /strong /moderately strong / of equal importance /moderately low/low /very low". As this process adhered to the principle of reciprocity, the reciprocals were calculated with the answers obtained.

The results were processed with the AHP technique, using the "ahpsurvey" package in R software (Cho 2018). As a result, a matrix of weights by factor and professional profile was obtained. Variables were then normalised in a common range between 0 and 1 (Eq. 1) and the COVID-19 social vulnerability index (COVID-19 SVI) was calculated.

$$V_{n,v} = \frac{V_v - V_{v,\min}}{V_{v,\max} - V_{v,\min}} \tag{1}$$

where $V_{n,v}$ is the normalised value v; V_v is the original value; $V_{v,\min}$. is the minimum value; and $V_{v,\max}$ is the maximum value.

The final result of the COVID-19 SVI is a number between 0 (very low vulnerability) and 1 (very high vulnerability). The formula used to calculate the "index" is described below (Eq. 2).

$$\begin{aligned}\text{Covid19SVI} = {} & (\text{normPD} \times \text{weightPD}) + (\text{normA} \times \text{weightA}) \\ & + (\text{normFeP} \times \text{weightFeP}) + (\text{normFoP} \times \text{weightFoP}) \\ & + (\text{normOvc} \times \text{weightOvc}) + (\text{normEduc} \times \text{weightEduc}) \\ & + ((1 - \text{normInc}) \times \text{weightInc}) \end{aligned} \quad (2)$$

This process was repeated for every scale of analysis proposed: district, BHA, census section and block. The results were then mapped with a qualitative legend with five intervals (very high, high, moderate, low and very low vulnerability), discretised by the quintile method to compare both the different factors and the multi-scale analysis.

Results

Survey Results

The results of the survey, which was responded by 404 subjects, reached a significant level of $p < 0.05$ with a 95% confidence interval. Forty-five per cent of the respondents were aged 18–40, 34.4% were aged 41–60 and 20% were over 60. Broken down by sex, 59.4% were female and 40.6% male. By professional profile, 24.8% of the respondents came from the healthcare sector, 20.5% from the geography sector, 16.6% from the social work sector and 1.7% from the Public Health Administration (PHA), which was added to the social work profile. The "other" category accounted for the remaining 36.3%. Most respondents (72.8%) lived in the city of Zaragoza and 87.9% said they had knowledge about the city. In addition, 18% of the people surveyed suggested other factors to be included, 11.1% added other comments and 24.7% left their email address to receive information about the results (Fig. 3).

There are hardly differences among the profiles surveyed (Fig. 4). The three most valued factors are overcrowding (0.223), population over 60 years old (0.218) and population density (0.204). However, despite the apparent "agreement" among professional profiles, there is a certain dispersion in the individual ratings of each group. This is especially noticeable in factors with the lowest weights, such as female population (0.073), income level (0.103), education level (0.08) and foreign population (0.099).

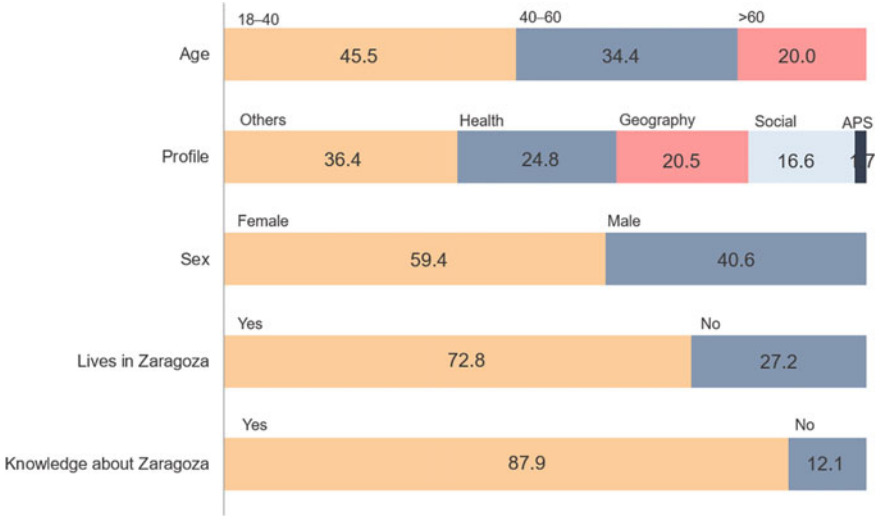

Fig. 3 General data of respondents

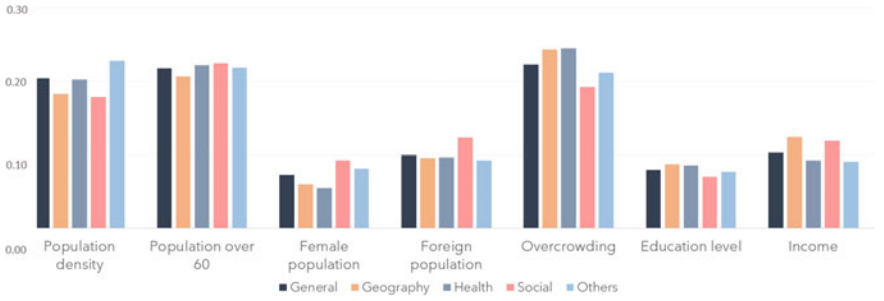

Fig. 4 Average weights assigned to vulnerability indicators per profile

Distribution and Characterisation of Social Vulnerability Factors at Different Scales

The spatial distribution of the variables shows a clear and identifiable pattern at all scales of analysis. However, the districts were seen as too large and varied to serve as a unit of analysis, as their mean values masked many internal differences. As such, this section will present the results of the BHA and census section for each factor and the index, while the latter will also be mapped at the block level.

BHAs in working-class districts have the highest vulnerability values of almost any variable, especially in the following factors: foreign population, overcrowding, education level and income level (Fig. 5). By contrast, BHAs in suburbs show values belonging to the first two quintiles for all variables except income level, which has

average values compared to the rest of the city. Population density values here are much lower than in the rest of the city.

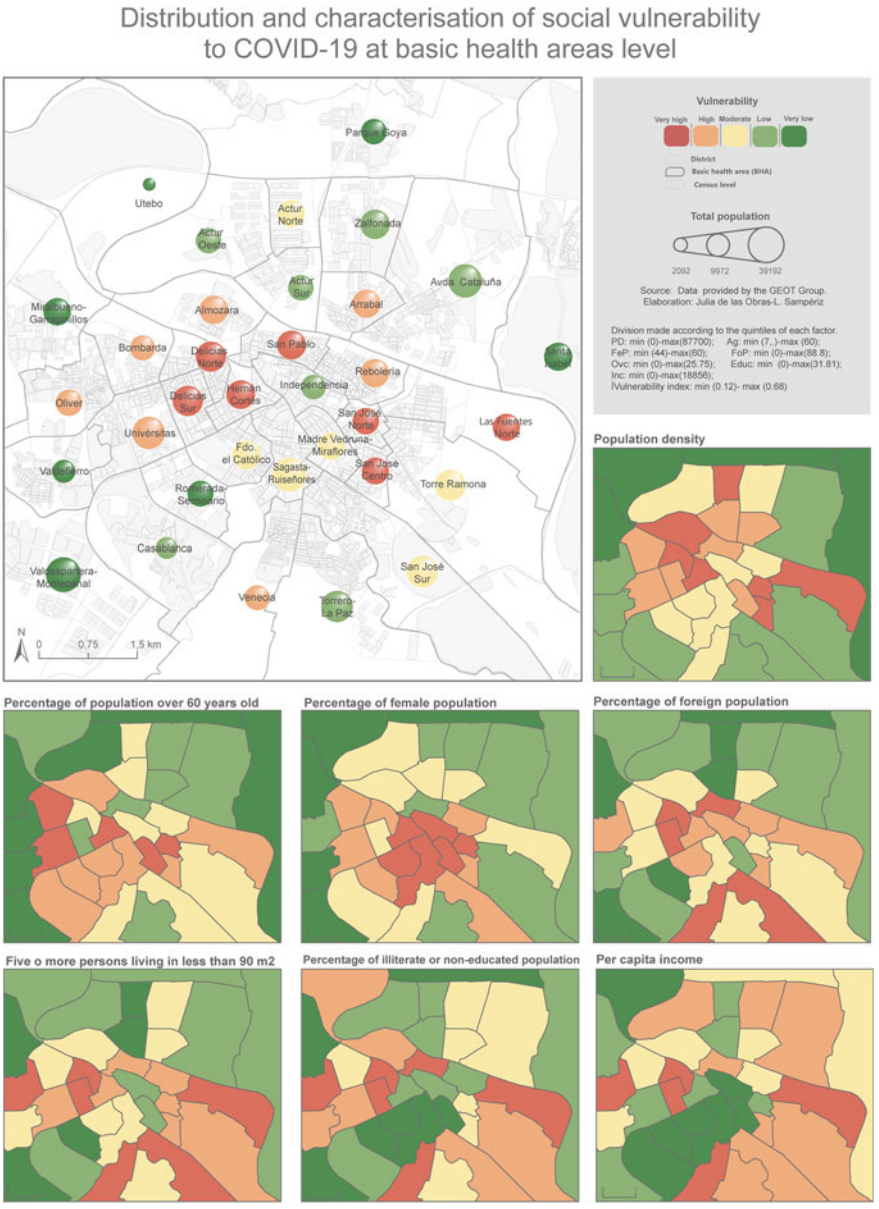

Fig. 5 Distribution and characterisation of social vulnerability to COVID-19 at the BHA scale by the GEOT Group

The pattern continues at the census section scale, but differences and nuances increase in the distribution (Fig. 6). Even though most sections with the highest vulnerability values belong to the BHAs, there are also cases where the average BHA values conceal a vulnerability hotspot. For instance, the relatively good value of the *Casablanca* BHA (0.29) hides the very high vulnerability of its census section (0.52). The opposite also occurs, as BHAs with very high vulnerability values can cover up internal differences. For example, the census section values of the *Univérsitas* BHA (0.50) range from very low vulnerability (0.26) to the worst value in the city (0.70).

This scale revealed the main hotspot for factors such as foreign population, overcrowding, education level and income level, since they all reach the highest values in the city in the same census sections, all of which belong to working-class districts. Transitional sectors are frequently found around them, fluctuating between high and low values, though there are also drastic changes, such as in the *El Rabal* and *Casablanca* districts. The other three factors show a different spatial distribution. The population density factor maintains the contrast between suburban sections and the rest of the city. The factor of age is the most dispersed throughout the city. Finally, the female population factor has a particular distribution, as the highest values are concentrated on an axis running from the historical centre to the *Univérsitas* district.

The distribution of vulnerability at the block scale (Fig. 7) remains broadly the same as in the census section, though higher resolution favours identification of transitions within vulnerable spaces, as seen in the *Delicias* and *Torrero* districts. Blocks with very high vulnerability are more easily identified in sectors with lower vulnerability, which in some cases is where the population over 60 resides.

Discussion

The impacts of COVID-19 do not affect all people equally, but socioeconomic, demographic and housing factors modulate their magnitude (Barrera et al. 2021; Seddighi 2020). This study has developed a methodology to measure social vulnerability by constructing a synthetic index using sociodemographic variables. The process adheres to the criteria proposed by Spielman et al. (2020): theoretical consistency, external consistency, practicality, transparency, interpretability, relevance and internal consistency. The index is based on the well-established theoretical approach of the SDHs, expressing vulnerability on a closed numerical scale (from 0 to 1). It has been built from freely available information and uses a standardised assessment procedure that can be replicated at multiple spatial scales. Moreover, if this index is compared with other national-level indices made by the *Atlas de Vulnerabilidad Urbana* (Ministerio de Movilidad n.d.)—*ISVUN-Global, ISVUN-Sociodemográfico*, the most vulnerable sections generally coincide, thereby verifying the former's suitability.

An essential resource resulting from this study is mapping, which can be key for COVID-19 management (Rose-Redwood et al. 2020). The spatial knowledge produced helps to understand complex phenomena in origin involving different

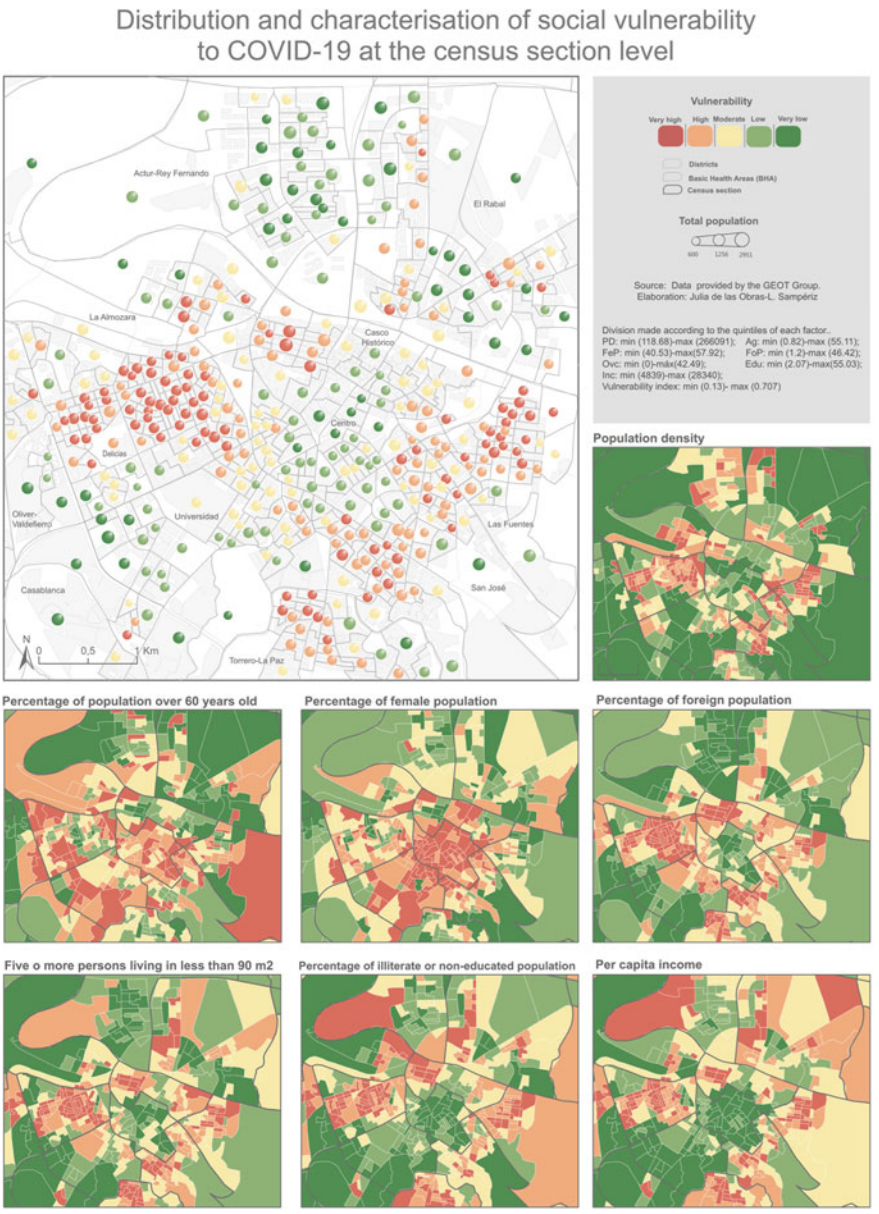

Fig. 6 Distribution and characterisation of social vulnerability to COVID-19 at census section scale by the GEOT Group

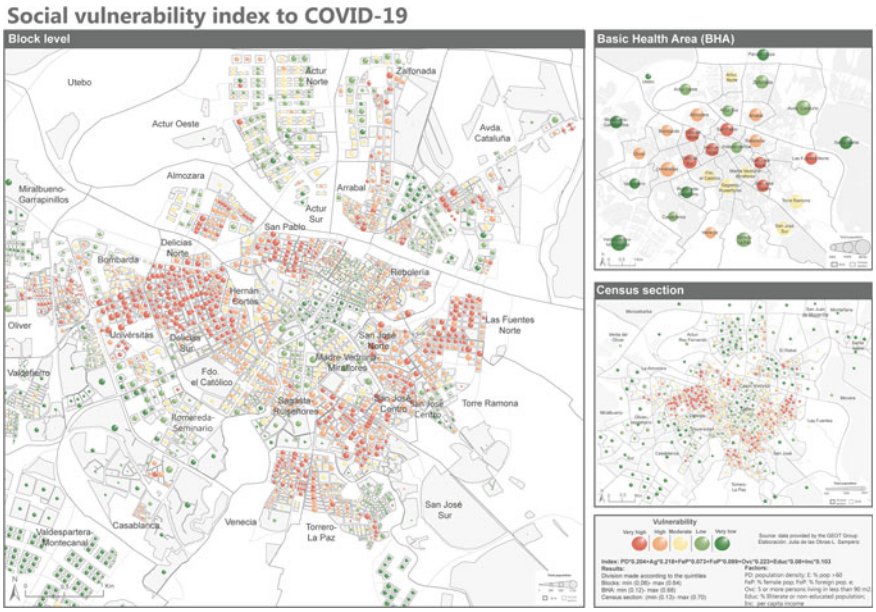

Fig. 7 Distribution of social vulnerability index to COVID-19

factors (Pueyo-Campos et al. 2016). For instance, this analysis reveals distribution patterns, which are fundamental for understanding the explanatory factors and therefore require action. In Zaragoza specifically, the distribution of vulnerability is closely related to the effects of urban transformation during the twentieth and twenty-first centuries (Escolano-Utrilla et al. 2018; de Miguel González 2014; Monclús 2013; Pérez-Moreno and Kurtz 2019). As such, the spatial pattern is characterised by alternating concentric rings reflecting socioeconomic and urban differences, thereby confirming the strong social component of COVID-19. At the centre of these rings is the *Independencia* sector, which has "low vulnerability". The commercial and service orientation of this part of the city, as well as the high price of land, as the latest data show (B.A. 2020), attracts upper-class residents to settle in large homes in a space with low population density. These characteristics are extended along small axes starting from the centre, such as *Sagasta* and *Gran Vía* (Escolano-Utrilla et al. 2018).

The second ring includes the city's working-class districts: *Delicias, Almozara, Las Fuentes, San José, Torrero* and *El Rabal*, which exhibit higher levels of vulnerability. This can be explained by the lack of planning and facilities in these districts during the population explosion in the twentieth century. The boom was particularly intense in the 1960s, when 5,000 social housing units (Pérez-Moreno and Kurtz 2019) and 60,000 new housing units are estimated to have been built without the necessary planning (de Miguel González 2014), with consequences that are still felt today. These districts are characterised by high population densities and poor-quality

housing, with a high ageing rate that is only reversed in some sectors by the arrival of foreign populations attracted by lower land prices (Escolano-Utrilla et al. 2018).

The last ring includes recently built districts located between the belts formed by the Z-30 and Z-40 roads. In contrast to the second ring, these neighbourhoods are characterised by lower population densities and a higher rate of young people who have left the city centre in recent years (Escolano-Utrilla et al. 2018). Thus, this ring has low levels of vulnerability.

Nevertheless, these rings show significant differences in terms of urban morphology, housing quality and urban space, which are decisive in population density and land prices, and therefore in other factors analysed. This leads to differences between and within districts and creates vulnerability hotspots due to the overlap of several factors: foreign population, overcrowding, income level and education level.

This study reveals that selecting the right unit of analysis is key to pandemic management. In the light of the results, the BHA appears too varied to serve as a unit of analysis, as its average values may mask a vulnerability hotspot and significant internal differences due to its large size. Instead, the census section seems to be the most appropriate unit of analysis due to its similarity to the block-level distributions and because it is a consistent and valuable source of information (Villarín Clavería and Segura Calero 2015), despite some problems such as it susceptibility to change.

Finally, it is necessary to consider what action should be taken to improve the situation. While taking this into account in short-term measures to prevent an increase in socioeconomic and health inequalities (World Health Organization 2021), it can also inform mid- and long-term strategies. For example, in the medium term, social policies are needed to target, monitor and support the most vulnerable groups, while long-term policies should aim to lower vulnerability levels, especially as the effects of COVID-19 are likely to exacerbate social inequalities (Ocaña et al. 2020). As such, this article argues for the need to improve social policy management and coordination, especially with regard to providing health services. It also calls for the implementation of strategies targeting factors that can serve as a driving force to improve the rest, such as support for education and inclusion. While urging continuous progress in gathering knowledge about the SDHs, it also proposes future lines of research, such as cross-referencing levels of vulnerability with incidence and fatality rate data to check if there is a correlation and monitoring vulnerability in these spaces to quantify the consequences of the pandemic.

Conclusions

The impacts of the COVID-19 pandemic will not affect all groups equally. Therefore, the creation and mapping of a vulnerability index can be crucial for pandemic-related decision-making and for identifying spatial distribution patterns. While constructing and applying this index of social vulnerability to COVID-19 (COVID-19 SVI), some conclusions of this research can be extrapolated to other case studies.

The factors with the highest values were overcrowding, age and population density, while the factors with the lowest values were female population, education level, income level and foreign population. However, there were a range of opinions when assessing the factors, particularly those with lower values. Nevertheless, this diversity does not reflect the different fields of knowledge so much as each respondent's individual opinion.

Once the multi-scale analysis was carried out, the importance of selecting the right scale for the analysis became clear. The conclusion was that the census section provides the optimal scale in this case, since a smaller scale would conceal internal differences in the neighbourhoods and preclude the proper detection of vulnerability hotspots.

Finally, social vulnerability to COVID-19 in Zaragoza is reflected in a spatial pattern of alternating concentric rings closely related to urban morphologies and the quality of housing and urban space. Areas dominated by the commercial sector show lower vulnerability, while working-class districts, which are more dense and populous, present high levels of vulnerability. Factors such as overcrowding, foreign population, education level and income level overlap in certain working-class areas, producing significant vulnerability hotspots.

In conclusion, this article advocates the measurement and spatialisation of vulnerability as a key management and decision-making tool. It also stresses the need to monitor socioeconomic developments and the social determinants of health and to implement policies to improve these spaces and prevent the situation from worsening. For all these reasons, further work on this subject is needed, as it has received too little study to date.

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