Health & Place 70 (2021) 102580

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

Social inequalities in mobility during and following the COVID-19 associated lockdown of the Madrid metropolitan area in Spain

Adrián Glodeanu [a,*], Pedro Gullón [b,c], Usama Bilal [d,e]

[a] Faculty of Geography and History, Universidad Complutense, Madrid, Spain
[b] Public Health and Epidemiology Research Group, School of Medicine and Health Sciences, Universidad de Alcalá, Alcalá de Henares, Madrid, Spain
[c] School of Global, Urban and Social Studies, RMIT University, Melbourne, Australia
[d] Urban Health Collaborative, Drexel Dornsife School of Public Health, Philadelphia, PA, USA
[e] Department of Epidemiology and Biostatistics, Drexel Dornsife School of Public Health, Philadelphia, PA, USA

ARTICLE INFO

Keywords:
COVID-19
Coronavirus
Mobility
Commuting
Quarantine
Inequalities

ABSTRACT

Spain has been one of the most affected regions by the COVID-19 worldwide, and Madrid its most affected city. In response to this, the Spanish government enacted a strict lockdown in late March 2020, that was gradually eased until June 2020. We explored differentials in mobility by area-level deprivation in the functional area of Madrid, before, during, and after the COVID-19 lockdown. We used cell phone-derived mobility indicators (% of the population leaving their area) from the National Institute of Statistics (INE), and a composite measure of deprivation from the Spanish Society of Epidemiology (SEE). We computed changes in mobility with respect to pre-pandemic levels, and explored spatial patterns and associations with deprivation. We found that levels of mobility before COVID-19 were slightly higher in areas with lower deprivation. The economic hibernation period resulted in very strong declines in mobility, most acutely in low deprivation areas. These differences weakened during the re-opening, and levels of mobility were similar by deprivation once the lockdown was completely lifted. Given the existence of important socioeconomic differentials in COVID-19 exposure, it is key to ensure that these interventions do not widen existing social inequalities.

1. Introduction

The novel coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has disrupted societies worldwide to levels not seen since the 1918 influenza pandemic. There have been at least 145 million COVID-19 cases and at least 3.1 million deaths globally as of April 23rd, 2021 (Johns Hopkins Coronavirus). To mitigate its impact, an ensemble of non-pharmaceutical interventions has been put into place, disrupting economic and social activities worldwide (Buchanan, 2020). One of these set of interventions, aimed at reducing contacts between individuals, includes physical distancing (Centers for Disease Contr, 2019). These interventions contain minimizing in-person work, education, and entertainment, along with restrictions to regional and metropolitan mobility. These restrictions have had an enormous impact in the progression of the pandemic, saving thousands of lives in many different settings (Flaxman et al., 2020).

Spain has been one of the most affected countries by the pandemic, with 78,000 deaths and 3.5 million cases between March 2020 and April 2021 (Johns Hopkins Coronavirus). Annual life expectancy during the first few months of the pandemic declined by 2 years in Madrid alone, while weekly life expectancy in Madrid and other regions of Spain declined by up to 10 years during the peak (Trias-Llimós et al., 2020). As part of the Spanish effort to mitigate the pandemic, lockdown measures were imposed due to the declaration of State of Alarm published on March 14, 2020 (Spain. Real Decreto 463, 2020), along with the declaration of an "economic hibernation" on March 28, 2020. These efforts resulted in an 80% reduction in public transit use (Moovit, 2020). As part of the re-opening strategy (called "New normality"), mobility started increasing on May 25th, but has not reached pre-pandemic levels. For example, travel to transit, retail, supermarkets, parks, and workplaces has remained low for Madrid (Google.D-19 Communit, 2020).

Given that the main purpose of these restrictions is to avoid exposure to SARS-CoV-2 in order to reduce the burden of infection, policies that increase mobility and forces workers to physically get to work, or that

* Corresponding author.
E-mail address: claudiug@ucm.es (A. Glodeanu).

https://doi.org/10.1016/j.healthplace.2021.102580
Received 25 October 2020; Received in revised form 26 April 2021; Accepted 27 April 2021
Available online 19 May 2021

lift restrictions too early, may increase exposure for both individuals, that need to continue being mobile, and the entire population, that will continue having increased incidence (Han et al., 2020). One of these social processes limiting the effectiveness of these interventions is social inequality (Bambra et al., 2020). Specifically, significant sectors of the economy cannot work remotely, especially those in essential retail, health care, public safety, and transportation, along with janitorial and other manual workers. Most of these occupations are low-wage occupations with very little bargaining power, and are in many cases fulfilled by migrants and minorities (Shadmi et al., 2020).

Previous studies have assessed changes in mobility associated with COVID-19 lockdowns (Bonaccorsi et al., 2020; Chang et al., 2020; Maire, 2020; Pullano et al., 2020). However, in this case, we propose to explore the changes in mobility patterns by area-level socioeconomic deprivation and using fine-grained mobility data (below the municipality level), allowing us to characterize urban mobility with a regional focus. We propose testing geographical segregation using cell phone data on small area-level socioeconomic status and daily mobility for the metropolitan area of Madrid, Spain, one of the most affected cities by COVID-19 worldwide. We hypothesize that geographic inequality patterns reported before COVID-19 are exacerbated as more disadvantaged areas had higher mobility during lockdown, and that this trend continued after the lifting of strict lockdown measures. As Spain currently undergoes a fourth wave of the pandemic, we believe this analysis can help inform future mobility restrictions to ensure health equity and better epidemic control.

2. Methods

2.1. Study setting

We use data on all 4341 census sections (called *secciones censales* in Spanish) and 310 mobility areas that compose the entire metropolitan area of Madrid, Spain. We define this area using the functional urban area definition, created by the Organization for Economic Co-operation and Development (Organisation for Economic, 2019). Almost 6 million people live in the area, where intra-urban mobility is done by private motorized transport (37%), public transit (35%), and walking (28%) (Comunidad de Madrid, 2014). Census sections are the smallest unit of aggregation of the Spanish census and house around 1500 people. Mobility areas are aggregations of 3000 and 50,000 people (Instituto Nacional de Est, 2020), with an average of 19,120 inhabitants (SD = 10, 737).

2.2. Mobility

We measured changes in mobility by small areas using data from the Spanish Statistical Office (INE) (Maire, 2020; Pullano et al., 2020). Mobility was quantified using cell phone location data, using data compiled by the INE from the major telephone operators in Spain (Instituto Nacional de Est, 2020, 2021). Mobility data has been shown to be more frequently and easily updatable data source to conventional travel surveys in mobility studies (Nyhan et al., 2016; Calabrese et al., 2011, 2013). The key indicator we used was the proportion of the population in a mobility area that left the mobility area during the day. In summary, a given person was considered as a resident if they were located in the same place between midnight and 6 a.m. Each person was then tracked from 10am to 4pm, and was considered to be in another area if they were there for more than 2 h. This destination area can be one where they live (understood as the one where they were from midnight to 6am) or a different one. This data is then used by INE to estimate the total population, number of people that stay in the area for the whole day, and number of people that moved to each of the other mobility areas.

We used this information, aggregated to mobility areas, to compute estimates of the proportion of the population that left their mobility area during the day, in five specific time frames corresponding to the phases of the pandemic (Appendix Table 1). For the pre-pandemic baseline, we used the average mobility patterns from the whole week of November 18–21, 2019. For the economic hibernation analysis, we used the average mobility data between March 30, 2020 and April 5, 2020 (considered as the valuable period of the most restrictive mobility measures). For the reopening period, we computed the average of mobility data for Phase 1 (from May 25, 2020 to May 31, 2020), Phase 2 (From June 8, 2020 to June 14, 2020) and New Normality (June 15, 2020 to June 20, 2020, last available date).

2.3. Socioeconomic deprivation index

We approximated area-level socioeconomic status using a socioeconomic deprivation index, a common strategy in health studies quantifying socioeconomic gradients (Tello et al., 2005; Bell and Hayes, 2012; Deonandan et al., 2000; Walker and Becker, 2005; Bell et al., 2007). We used a socioeconomic deprivation index developed by the Spanish Epidemiology Society (Sociedad Española de Epidemiología, SEE) using data from the 2011 Spanish census (Cebrecos et al., 2018; Duque et al., 2020). This index included six census indicators selected through the use of principal component analysis (see Appendix table 2 for the list of final indicators). These six indicators included variables on occupation (manual workers and occasional salaried workers), unemployment, education (incomplete compulsory education, both in the general population and in the population aged 16–29), and lack of internet access. The final deprivation index was constructed by extracting the first component of the principal components' analysis, standardized to a mean of 0 and a deviation of 1. More details are available in (Duque et al., 2020). Since this index was available at the census section level, we aggregated the index to the mobility area level by averaging the value of each census section in each mobility area, weighted by the population of the census section. We did this by conducting a spatial join of mobility areas and census sections, as a mobility area contains one or more census sections.

2.4. Analysis

The main objective of this analysis was to study socioeconomic differentials in mobility before, during, and after the lockdown in the metropolitan area of Madrid. We conducted this analysis in three steps. First, we explored the distribution of mobility, both over time through the five periods, and over space, by using choropleth maps. We also computed a summary indicator of changes, by subtracting the mobility in each lockdown period compared to the pre-pandemic week. We classified areas using Jenks or Natural Breaks (Jenks, 1967; Brewer and Pickle, 2002). This method seeks to minimize the average deviation within categories and to maximize heterogeneity between categories. Second, we examined the association between socioeconomic deprivation and mobility and changes in mobility by fitting a linear regression of mobility or changes in mobility as the dependent variable and socioeconomic deprivation as the independent variable. We fitted an univariate model since our main objective was to describe how mobility or changes in mobility differed by levels of socioeconomic deprivation, not necessarily to establish a causal relationship adjusted for confounders. We also created a bivariate map showing both socioeconomic deprivation and changes in mobility, and classified areas into either low deprivation and low mobility (if the specific area had a deprivation and mobility below the 20th percentile) or high deprivation and high mobility (if the specific area had a deprivation and mobility above the 80th percentile).

This study is based on bibliographic, statistical and cartographic data collected by Spanish Cadastre, Spanish National Institute of Geographic (IGN), Spanish Epidemiology Society (SEE) and Spanish Statistical Office (INE). Statistical analysis was conducted using R 3.6.2 (R Core Team, 2020). Cartographical analysis was done in QGIS 3.2.3 (QGIS

Table 1
Mobility and changes in mobility by phase and deprivation.

	% people going outside their residential area				
	Previous N.	Economic H.	Phase 1	Phase 2	New Normality
Less deprived	37,71	8,61	16,99	18,86	21,13
Average deprivation	36,25	8,78	17,32	18,88	21,12
More deprived	34,90	8,52	16,88	18,26	20,48
	Relative Change in % people going outside their residential area compared to Previous Normality				
	Previous N.	Economic H.	Phase 1	Phase 2	New Normality
Less deprived	Reference	−77,15	−54,95	−49,98	−43,97
Average deprivation	Reference	−75,79	−52,22	−47,91	−41,75
More deprived	Reference	−75,60	−51,62	−47,67	−41,33
	Relative Change in % people going outside their residential area compared to previous phase				
	Previous N.	Economic H.	Phase 1	Phase 2	New Normality
Less deprived		−77,15	97,19	11,03	12,03
Average deprivation		−75,79	97,30	9,03	11,82
More deprived		−75,60	98,26	8,17	12,11

Footnote: relative changes are calculated as 100*(Mobility in new period – mobility in baseline period)/mobility in baseline period.

Development Team, 2020). Our final datasets are available for public download (OSF Repository with open data from the project).

3. Results

Table 1 and Appendix Fig. 1 shows a detailed description of the urban mobility patterns registered during the COVID-19 pandemic in the 310 mobility areas of the Madrid metropolitan area. In the pre-pandemic period, an average of 36% of the population left their mobility area daily. During the strictest lockdown, the economic hibernation period, this declined to 9%, and increased slightly as the economy reopened, recovering to 17%, 19%, and 21% in the first and second phases and during the complete reopening. Importantly, mobility was heterogeneous by area, with the % leaving their mobility area daily ranging from 18 to 61% in the pre-pandemic week, and from 4% to 15% in the economic hibernation period.

Fig. 1 shows the change in mobility from the pre-pandemic week to the economic hibernation stage, the most restrictive lockdown, for all mobility areas of the metropolitan area of Madrid. We found a heterogeneous spatial pattern. First, mobility declined sharply in the central districts of Madrid, where most mobility areas had a decline of mobility of more than 80%. Suburban areas were very heterogeneous, with some, especially in the North and West, having steep drops similar to the central parts of Madrid. On the other hand, the southern part of the city

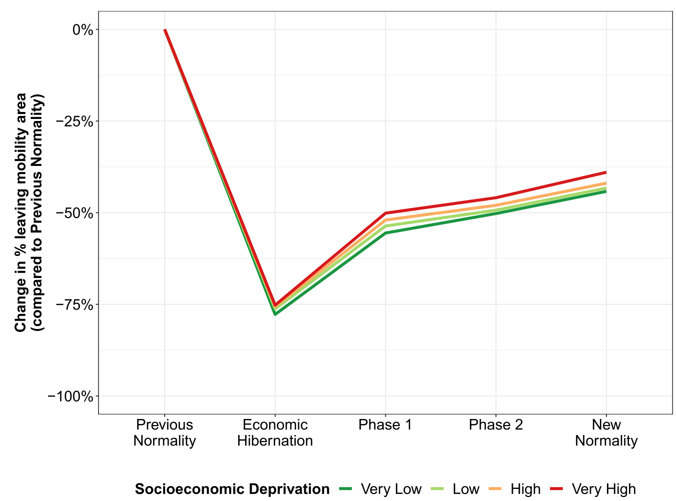


Fig. 2. Mobility drop by phase compared to previous normality and deprivation during the COVID-19 lockdown and re-opening in Madrid
Footnote: deprivation was defined using tertiles.

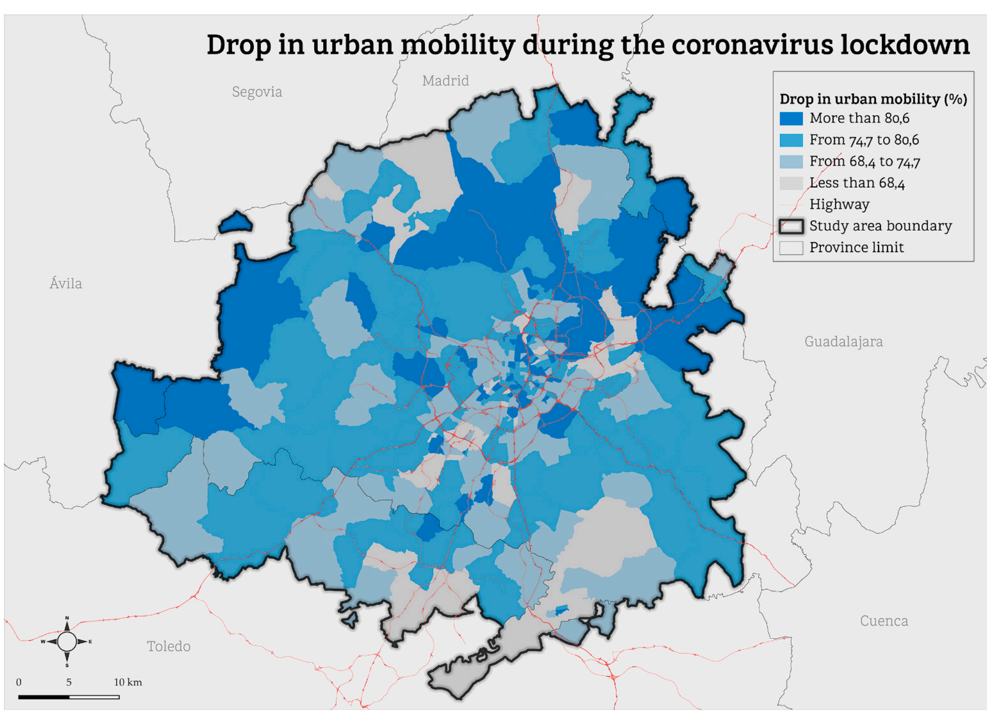


Fig. 1. Changes in mobility comparing previous normality to the economic hibernation period (lockdown)
Footnote: categories of drop in urban mobility (%) were defined using the jenks or natural breaks method.

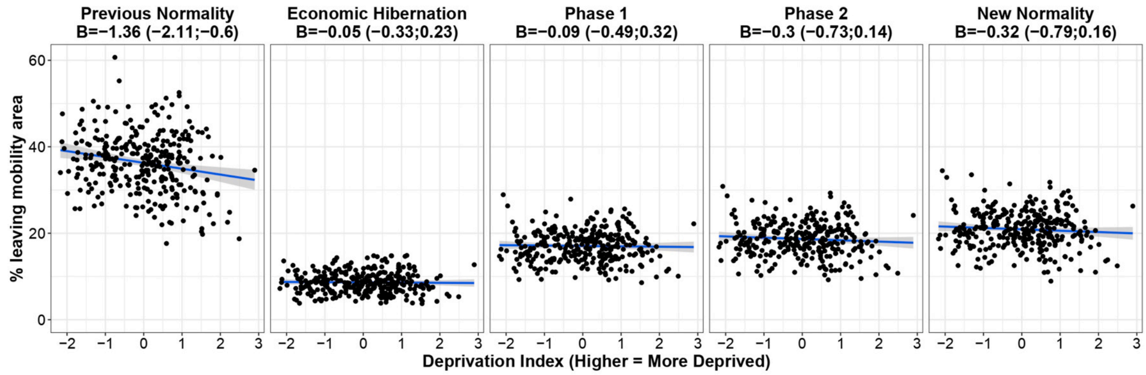


Fig. 3. Mobility and deprivation during the five periods of this study in Madrid
Footnote: coefficients and 95% confidence intervals come from a linear regression model of mobility on deprivation.

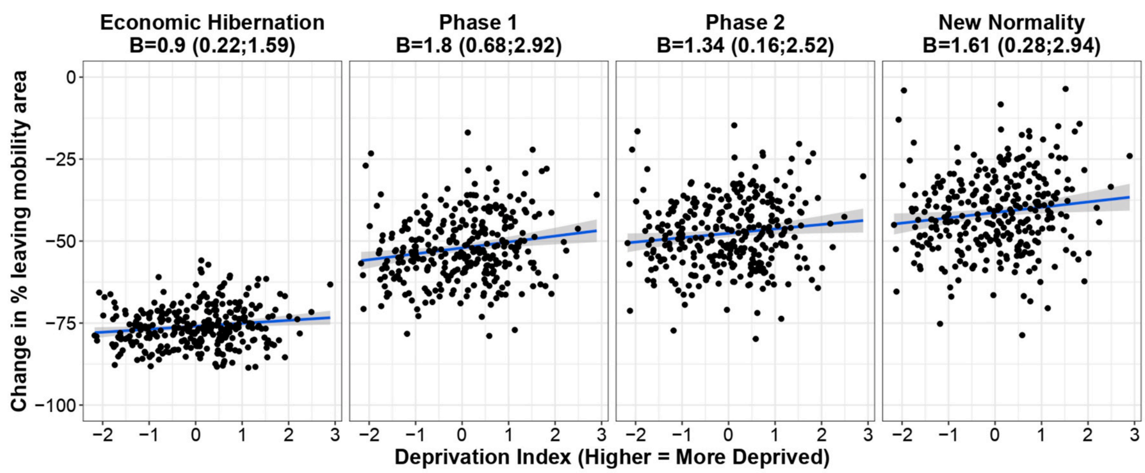


Fig. 4. Changes in mobility compared to previous normality and deprivation in Madrid
Footnote: coefficients and 95% confidence intervals come from a linear regression model of changes in mobility on deprivation.

and suburban areas South of Madrid had the weakest drops in mobility, of less than 67%.

Fig. 2 shows the trends in changes in mobility during the four lockdown periods, compared to baseline, by levels of deprivation. First, we found that in the pre-pandemic period mobility was slightly lower in more deprived areas. However, we found that mobility was consistently higher in the same more deprived areas during all pandemic phases. We found a 77.2% decline in mobility during the economic hibernation period in the less deprived areas, compared to a 75.6% decline in the more deprived areas. This pattern persisted during the re-opening phase, although differences between areas declined over time and were negligible in the last phase.

Figs. 3 and 4 (also Appendix Fig. 2) show the association between mobility and changes in mobility and deprivation. We found that, previous to the COVID-19 pandemic, a 1 SD increase in deprivation was associated with 1.36% lower mobility (95% CI -2.11 to −0.60). This association changed during the lockdown, so that a 1 SD increase in deprivation was associated with no differences in mobility (β = 0.05%, 95% CI -0.33%–0.23%). Similarly, during subsequent phases there was no association between deprivation and mobility. However, we found that, compared to the previous normality, changes in mobility associated with lockdowns and subsequent re-opening phases were marked. First, during the economic hibernation period, a 1 SD increase in socioeconomic deprivation was associated with a 0.9% increase in mobility (95% CI 0.22 to 1.59), as compared to the previous normality. This association was strengthened during the re-opening, as a 1SD increase in deprivation was associated with a 1.8%, 1.3% and 1.6% increase in mobility during phases 1 and 2 and new normality, respectively, as compared to the previous normality.

Fig. 5 shows the spatial co-occurrence of high/low levels of deprivation stronger/weaker changes in average urban mobility levels during the economic hibernation period. Specifically, we found areas of low deprivation and lower mobility in the central areas of the city and in the Northern and Western suburbs. We also found areas of high deprivation and high mobility in the southern areas of the city and suburbs.

4. Discussion

In this study of urban mobility before, during, and after the lockdown due to COVID-19 in the metropolitan area of Madrid, we evidenced a heterogeneous mobility landscape that was strongly socially patterned. First, we found that mobility was very low during the economic hibernation period, with declines of up to 89% compared to baseline, and remained low during the reopening, with declines of up to 80%, compared to baseline, in the last phase of reopening. Second, we found that this heterogeneity was spatially patterned, with the central parts of the city, and the northern and western suburbs, having the steepest drops in mobility. On the other hand, the southern parts of the city and southern suburbs had the weakest drops in mobility. This spatial pattern follows a similar pattern as the deprivation index, suggesting that more deprived areas experienced a weaker drop in mobility, or that less deprived areas experienced a stronger drop in mobility. This social pattern was especially marked during Phases 1 and 2 of the re-opening, as compared to the strictest lockdown and the full re-opening.

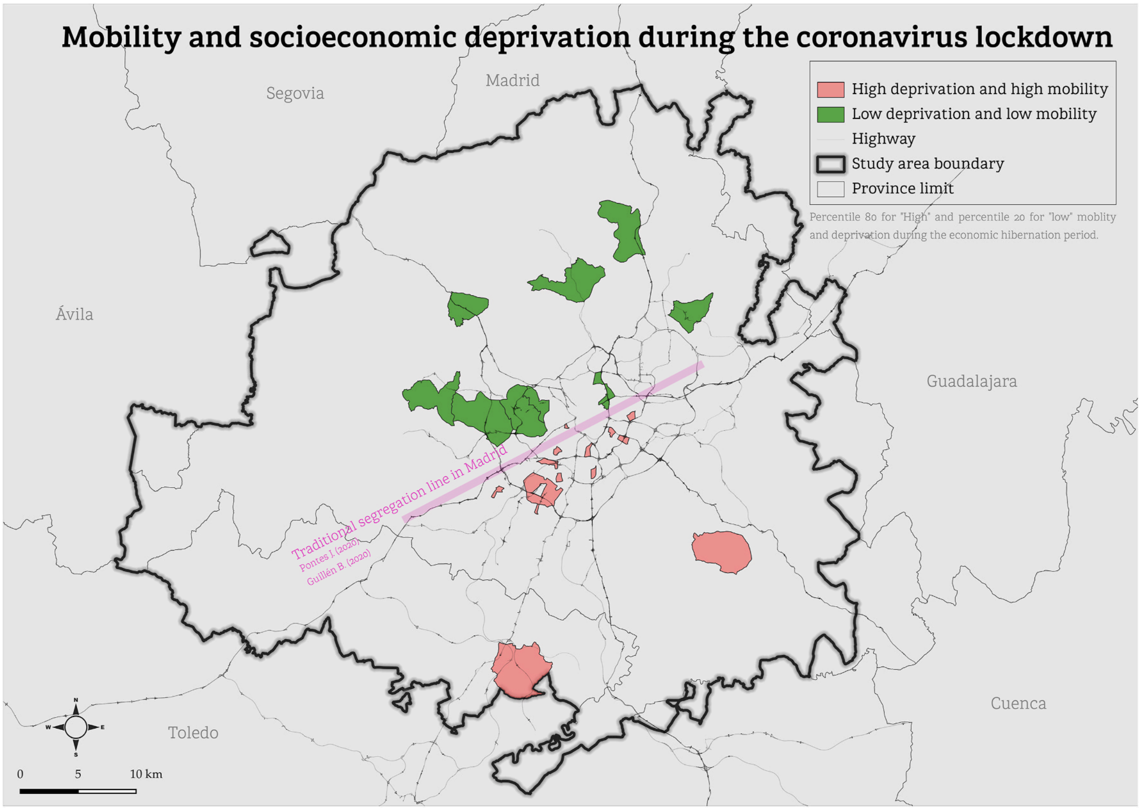


Fig. 5. Localization of mobility areas with spatial co-occurrence of deprivation and mobility in Madrid during the pandemic.
Footnote: high deprivation and mobility areas were defined as those above the 80th percentile for both variables. Low deprivation and mobility areas were defined as those below the 20th percentile for both variables.

The Center-North-West vs South and Southeast pattern we found represents the usual segregation pattern of the city of Madrid. Specifically, Madrid has been, since after the 19th century, characterized by a spatial border between the rich north and the poor south that, during the last century has been consolidated as a northeast – southeast one (Pontes, 2020; Guillén, 2015). This generalization is important to understand the factors behind the results in this manuscript, as the ring road M30 and the A2 highway (in the Northeast) creates the main border between the more vulnerable neighborhoods in the South, versus the rest of the central part of the city. The segregation of Madrid has been exacerbated following the 2008 recession (Rubiales Pérez, 2016).

In the baseline week, named Previous Normality here, we observed a pattern of higher mobility in less deprived areas. However, during the strictest part of the lockdown this pattern was reversed, with higher mobility in more deprived areas. During this part, only people working in essential services were allowed to even leave their home for work purposes, while everyone else was restricted to teleworking or not working at all. Since essential workers from sectors such as healthcare, grocery, manufacturing, transportation or public safety have to continue working in-person, with limited accommodations, people working in these sectors will continue being exposed. Essential workers are vital to the well-being and survival of the population during the pandemic, but, at the same time, they are highly vulnerable to the economic and health risks posed by the pandemic (Schneider and Harknett, 2020). Specifically, previous studies have shown that low wage workers were two or three times more likely than high wage workers to not having access to personal protective equipment and other measures that prevent the transmission of COVID-19, with 65% of workers labelled as essential reporting being unable to practice social distancing (Hammonds and Kerrissey, 2020). In summary, and as reported elsewhere (Sy et al., 2020; Ayyub, 2020; Jay et al., 2020), and consistent with our results, social distancing seems to be more available for those in positions (or living in areas) of more privilege.

As lockdown measures were progressively lifted, these patterns worsened, and the social patterning of mobility strengthened. In phases 1 and 2, the main difference in terms of working and social distancing conditions changed from the dichotomy between essential and non-essential workers to commuters and teleworkers. People who could telework were able to stay at home, reducing exposure to COVID-19, while people who work in places that need in-person work continued being more exposed. The differences we observed in mobility by deprivation in the re-opening phases are most likely a reflection of the social class of workers that can or cannot telework. This is similar to findings reported in Italy, as the local structure of the labor market mainly explained the variations in urban mobility in Italy's first lockdown (Gauvin et al., 2020). Hence, according to a report from the Spanish National Bank, teleworking is far more common among people with permanent jobs as compared to temporal workers, with 34% of workers in permanent jobs teleworking for more than half of their work days, as compared to 10% for temporal workers (Banco de España, 2020). Apart from the working conditions and lack of telecommuting opportunities, other inequalities are underlying the COVID-19 pandemic, such as food insecurity, unstable housing, or domestic violence (Sy et al., 2020). However, there is a limited number of studies that analyze the intersection of socioeconomic conditions and the vulnerability that it is introduced by inequalities (Blow, 2020; Mikolai et al., 2020). There are even fewer that, spatially, describe the differences in essential commuting during the lockdown period or the peak of the pandemic (Klein et al., 2020; Quealy, 2020), even though wealth inequality has been studied as a health determinant in the literature (Ezzati et al., 2008; Krisberg, 2016).

Our results are similar to those reported in other settings. Therese, K. et al. (Sy et al., 2020) found a socioeconomic and racial/ethnic component in subway travelling while the pandemic; areas with the lower median income, a greater percentage of individuals who identify as non-white and/or Hispanic/Latino, a greater percentage of essential workers, and a greater percentage of healthcare workers had more subway use during the pandemic. Ayyub, 2020 (Ayyub, 2020) sheds a light on the second component of the vulnerability imposed by COVID-19; there are people for whom staying home means a drop in their income and familiar wage problems. This is especially important for the informal economy, and some sectors such as construction and agriculture that rely on in-person labor. It is estimated that around 2 to 4 million people in Spain have entered poverty during the lockdown (Sánchez, 2020) due to working in the informal economy. Last, a number of studies using data at both the neighborhood and municipality levels in the US, France, and Italy have shown results consistent to ours, with areas of higher socioeconomic deprivation experiencing weaker drops in mobility with COVID-19 lockdowns (Pullano et al., 2020; Jay et al., 2020; Gauvin et al., 2020; Weill et al., 2020).

Our study has several limitations. First, our baseline mobility data was limited to November 2019, in a different season, meaning that mobility patterns may have changed beyond the role of the lockdown. Second, we lacked a mobility estimate for the complete re-opening phase, and relied on the week before that re-opening fully took place. This does not allow us to estimate the heterogeneity and social patterning of mobility during the actual reopening. Our deprivation index was calculated using data from the 2011 census, and there may be a degree of misclassification. However, as shown in previous studies, inequalities in Madrid continue increasing (Fundación FOESSA, 2019), and segregation continues intensifying (Picardo Costales, 2018), so our results represent a conservative estimation of these inequalities. Finally, the modifiable areal unit problem (MAUP) could have been a problem of this project's methodology as it introduces statistical bias that can impact the results. Nevertheless, the mobility areas were created to counteract this possible phenomenon. Our study also has several strengths, including the use of fine-grained mobility and socioeconomic deprivation data, all publicly available, enhancing reproducibility and useability in other studies.

As Spain entered a second, a third and a fourth COVID-19 wave with large outbreaks in Madrid in September 2020, February 2021 and April 2021, the regional government of Madrid started a series of neighborhood-level lockdowns that prohibited non-work-related mobility. However, these lockdowns still forced workers that cannot telework to be physically present at their job locations, frequently outside their residential neighborhood. Our results show that these types of policies may have negative impacts on poorer neighborhoods, as their residents are more likely to have to work in person.

Funding

UB was supported by the Office of the Director of the National Institutes of Health under award number DP5OD26429. PG was supported by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 842957. The funding sources had no role in the analysis, writing or decision to submit the manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

We want to acknowledge the Instituto Nacional de Estadística (INE) and the Sociedad Española de Epidemiología (SES) for making their mobility and deprivation data publicly available.

Appendix

Appendix Table 1
five phases used in this study

Phase	Date(s) or starting date	Restrictions
Previous Normality	Average mobility patterns taken from November 18–21, 2019 (chosen as an indicator of a normal labour week)	No restrictions
Economic Hibernation	Mar 30-Apr 5, 2020	The period when the most restrictive policies were taken (Spain. Real Decreto-ley 10, 2020)
Re-Opening (Phase 1)	May 25–31, 2020	People could start meeting in groups of ten members and small stores started to re-open (Spain. Orden SND/399, 2020)
Re-Opening (Phase 2)	June 8–14, 2020	Residents could go walking or playing sports at any hour of the day, they could meet in groups of fifteen people and malls could open. (Spain. Orden SND/414, 2020)
New Normality	June 15–20, 2020	No restrictions, but with new hygiene and social distancing rules and mask regulations (Spain. Real Decreto-ley, 2020)

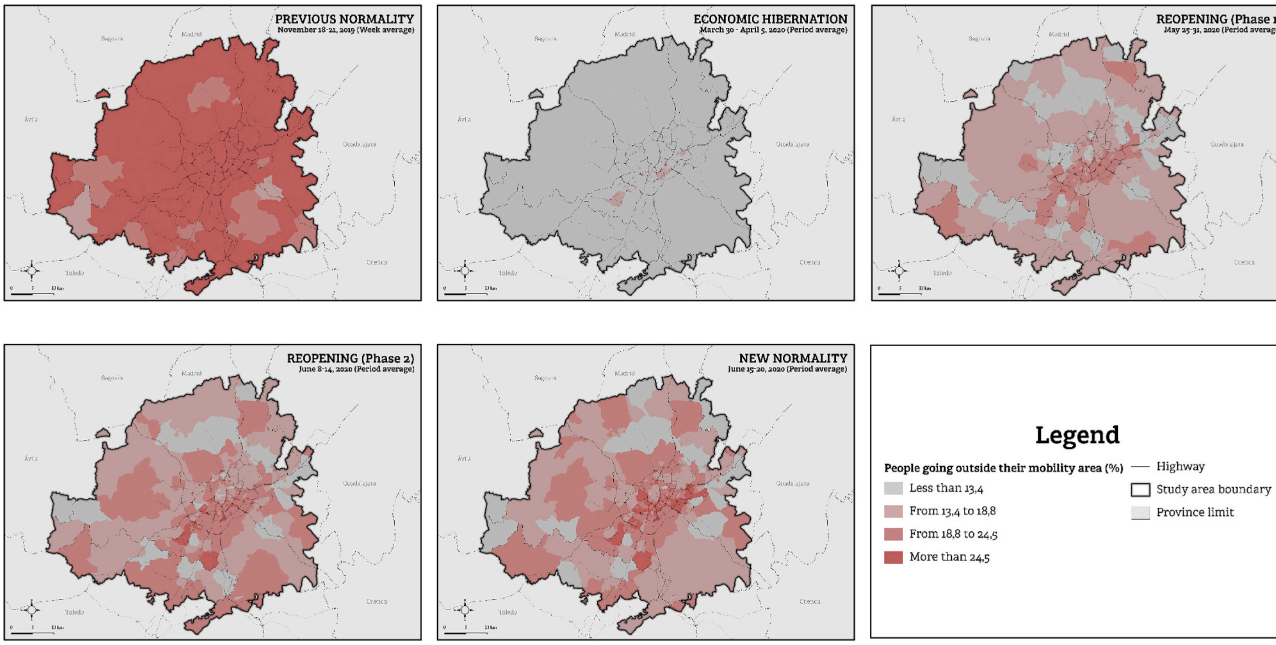
Footnote: Different periods of the COVID-19 pandemic legislation and measures in Spain.

Appendix Table 2
Variables used for the deprivation index

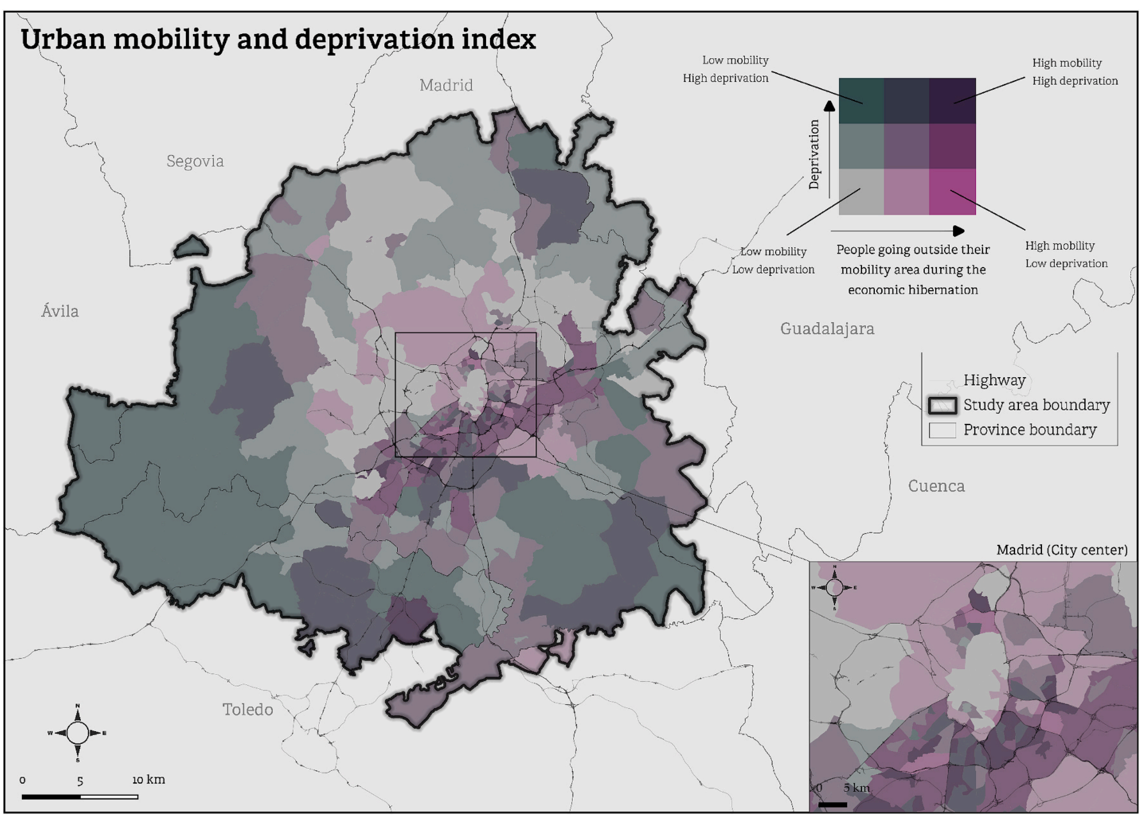
Variable	Numerator	Denominator
Manual worker	Population (>16) employed or unemployed which worked in places coded according to CNO-11 as 5 + 6+7 + 8+9[1]	Population (>16) employed or unemployed
Occasional salaried	Population (>16) employed or unemployed that worked before eventually nor temporally	Population (>16) employed or unemployed
Unemployment	Population (>16) unemployed and who is looking for the first job	Labour force
Insufficient instruction	Population (>16) illiterate, with less than 5 years of school and those who did not reached finishing compulsory education	Population (>16)
Insufficient instruction in young people	Population (16–29) illiterate, with less than 5 years going to school and those who did not reached finishing compulsory education	Population (16–29)
Households with no internet access	Households with no internet service contracted	Total number of households

Variables used in the 2011 SES′ socioeconomic deprivation index (Data source: https://www.seepidemiologia.es/documents/dummy/ManualIP2011.pdf).

[1] The Clasificación Nacional de Ocupaciones 2011 (CNO-2011) (National Occupation Classification, 2011) code's meaning is: 5 (Restauration, personal, protection and selling services), 6 (Workers in farming, livestock, forestry or fishery), 7 (people employed as craftsman, manufacturing and construction), 8 (people working as machine or assembly operators) and, finally, 9 (essential workers).



Appendix Fig. 1. mobility by area during the five periods in this study in Madrid.



Appendix Fig. 2. mobility and deprivation in Madrid.

References

Ayyub, R., 2020. Social Distancing Is a Privilege. Foreign Policy. March 28. Available online: https://foreignpolicy.com/2020/03/28/social-distancing-is-a-privilege/. (Accessed 20 July 2020).

Bambra, C., Riordan, R., Ford, J., Matthews, F., 2020. The COVID-19 pandemic and health inequalities. J. Epidemiol. Community 74 (11). Available online: https://jech.bmj.com/content/74/11/964. Accessed on September 2020.

Banco de España, 2020. El teletrabajo en España. Boletín económico del Banco de España. Available online: https://www.bde.es/bde/es/secciones/informes/boletines/articulos-analit/. (Accessed 21 July 2020).

Bell, N., Hayes, M.V., 2012. The vancouver area neighbourhood deprivation index (vandix): a census-based tool for assessing small-area variations in health status. Can. J. Public Health 103 (2), 28–32. Available online: https://www.jstor.org/stable/41995686. (Accessed 3 August 2020).

Bell, N., Schuurman, N., Hayes, M.V., 2007. Using GIS-based methods of multicriteria analysis to construct socio-economic deprivation indices. Int. J. Health Geogr. 6 (17). Available online: https://link.springer.com/article/10.1186/1476-072X-6-17#citeas. (Accessed 3 August 2020).

Blow, M., 2020. C. Social Distancing Is a Privilege. April 5. The New York Times. Available online: https://www.nytimes.com/2020/04/05/opinion/coronavirus-social-distancing.html. (Accessed 21 July 2020).

Bonaccorsi, G., Pierri, F., Cinelli, M., et al., 2020. Economic and social consequences of human mobility restrictions under COVID-19. Proc. Natl. Acad. Sci. U. S. A. 117 (27), 15530–15535. https://doi.org/10.1073/pnas.2007658117. Available online.

Brewer, C., Pickle, L., 2002. Evaluation of methods of classifying epidemiological data on choropleth map in series. Ann. Assoc. Am. Geogr. 92 (4), 662–680.

Buchanan, L., 2020. 54 Ways Coronavirus Has Changed Our World. May 27. The New York Times. Available online: https://www.nytimes.com/interactive/2020/05/27/sunday-review/coronavirus-effects.html. (Accessed 16 July 2020).

Calabrese, F., Colonna, M., Lovisolo, T., Parata, D., 2011. Real-time urban monitoring using cell phones: a case study in rome. IEE Transactions on intelligent transportation systems 12 (1), 141–151. Available online: http://hdl.handle.net/1721.1/101712. (Accessed 31 July 2020).

Calabrese, F., Diao, M., Di Lorenzo, G., Jr, J.F., Ratti, C., 2013. Understanding individual mobility patterns from urban sensing data: a mobile phone trace example. Transport. Res. C Emerg. Technol. 26, 301–313. https://doi.org/10.1016/j.trc.2012.09.009. Available online: (Accessed 31 July 2020).

Cebrecos, A., Felícitas Domínguez-Berjón, M., Duque, I., et al., 2018. Geographic and statistic stability of deprivation aggregated measures at different spatial units in health research. Appl. Geogr. 95, 9–18.

Centers for Disease Control and Prevention. "Social Distancing. Keep a Safe Distance to Slow the Spred". Available online: https://www.cdc.gov/coronavirus/2019-ncov/prevent-getting-sick/social-distancing.html (Accesed on July 20, 2020).

Chang, S., Pierson, E., Wei Koh, P., et al., 2020. Mobility network models of COVID-19 explain inequalities and inform reopening. Nature 589, 82–87. Available online: https://www.nature.com/articles/s41586-020-2923-3.

Comunidad de Madrid, 2014. Encuesta sintética de movilidad en la Comunidad de Madrid-ESM14. December. Available online: https://www.crtm.es/media/519661/esm_2014.pdf. (Accessed 20 July 2020).

Deonandan, R., Campbell, K., Ostbye, T., Tummon, I., Robertson, J., 2000. A comparison of methods for measuring socio-economic status by occupation or postal area. Chron. Dis. Can. 21 (3), 114–118. Available online: https://pubmed.ncbi.nlm.nih.gov/11082347/. (Accessed 3 August 2020).

QGIS Development Team, 2020. QGIS Geographic Information System. Open Source Geospatial Foundation Project. Available online: http://qgis.osgeo.org.

Duque, I., Felícitas Domínguez-Berjón, M., Cebrecos, A., et al., 2020. Índice de privación en España por sección censal en 2011. Gac. Sanit. 35 (2), 113–122.

OSF Repository with open data from the project. Available online: https://osf.io/35r6d/.

Ezzati, M., Friedman, A.B., Kilkarni, S.C., Murray, C.J.L., 2008. The reversal of fortunes: trends in county mortality and cross-county mortality disparities in the United States. PLoS Med. 5 (5), e119. https://doi.org/10.1371/journal.pmed.0050066. Available online: (Accessed 23 July 2020).

Flaxman, S., Mishra, S., Gandy, A., et al., 2020. Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. Nature 584, 257–261. https://doi.org/10.1038/s41586-020-2405-7. Available online: (Accessed 24 July 2020).

Fundación FOESSA, 2019. Informe sobre exclusión y desarrollo social en Madrid. Resultados de la Encuesta sobre Integración y Necesidades Sociales 2018. Available online: https://caritas-web.s3.amazonaws.com/main-files/uploads/sites/16/2019/10/MADRID-VIII-Informe-FOESSA.pdf. (Accessed 29 September 2020).

Gauvin, L., Bajardi, P., Pepe, E., et al., 2020. Socieconomic determinants of mobility responses during the first wave of COVID-19 in Italy: from provinces to neighbourhoods (Preprint) medRxiv. Available online: https://www.medrxiv.org/content/10.1101/2020.11.16.20232413v1.full.pdf+html.

Google, 2020. COVID-19 community mobility reports. Available online: https://www.gstatic.com/covid19/mobility/2020-07-17_ES_Mobility_Report_es.pdf. (Accessed 22 July 2020).

Guillén, B., 2015. "La brecha entre ricos y pobres en Madrid, la más grande de Europa". El País. Article (in press). https://elpais.com/ccaa/2015/10/09/madrid/1444416065_033414.html. (Accessed 20 August 2020).

Hammonds, C., Kerrissey, J., 2020. "We Are Not Heroes Because it Is Not a Choice", A Survey of Essential Workers' Safety and Security during COVID-19. Umass Amherst Labor Center. Available online: https://www.umass.edu/lrrc/sites/default/files/Western%20Mass%20Essential%20Worker%20Survey%20-%20May%202020.pdf. (Accessed 19 July 2020).

Han, E., Mei Jin Tan, M., Turk, E., et al., 2020. Lessons learnt from easing COVID-19 restrictions: an analysis of countries and regions in Asia Pacific and Europe. Lancet. Available online: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)32007-9/fulltext. (Accessed 13 October 2020).

Instituto Nacional de Estadística (Spanish Statistical Office-SSO), 2020. Analysis of population mobility during the COVID-19 state of alarm based on mobile phone positioning. Technical project. Available online: https://www.ine.es/en/covid/exp_movilidad_covid_proyecto_en.pdf. (Accessed 10 March 2021).

Instituto Nacional de Estadística (Spanish Statistical Office-SSO), 2021. Statistical information for the analysis of the impact of the COVID-19 crisis. Available online: https://www.ine.es/en/covid/covid_movilidad_en.htm#tablas_resultados.

Jay, J., Bor, J., Nsoesie, E.O., et al., 2020. Neighbourhood income and physical distancing during the COVID-19 pandemic in the United States. Nature human behaviour 4 (12), 1294–1302.

Jenks, G.F., 1967. The data model concept in statistical mapping. Int. Yearb. Cartogr. 7, 186–190.

Johns Hopkins Coronavirus Resource Center. COVID-19 dashboard by the center for systems science and engineering (CSSE). Web: https://coronavirus.jhu.edu/map.html.

Klein, B., LaRock, T., McCabe, S., Torres, L., Privitera, F., Lake, B., Kraemer, M.U.G., Brownstein, J.S., Lazer, D., Eliassi-Rad, T., Scarpino, S.V., Chinazzi, M., Vespignani, A., 2020. Assessing Changes in Commuting and Individual Mobility in Major Metropolitan Areas in the United States during the COVID-19 Outbreak. March 31. Northeastern University, Network Science Institute. Available online: https://www.networkscienceinstitute.org/publications/assessing-changes-in-commuting-and-individual-mobility-in-major-metropolitan-areas-in-the-united-states-during-the-covid-19-outbreak.

Krisberg, K., 2016. Income inequality: when wealth determines health: earnings influential as lifelong social determinant of health. Nation's Health 46 (8), 1–17. Available online: http://thenationshealth.aphapublications.org/content/46/8/1.1.

Maire, J., 2020. Impact of COVID-19 lockdowns on individual mobility and the importance of socioeconomic factors. PIIE (Policy Brief 20-14). Available online: https://www.piie.com/publications/policy-briefs/impact-covid-19-lockdowns-individual-mobility-and-importance.

Mikolai, J., Keenan, K., Kulu, H., 2020. Intersecting household level health and socio-economic vulnerabilities and the COVID-19 crisis: an analysis from the UK. SSM-Population Health. Journal pre-proof. https://doi.org/10.1016/j.ssmph.2020.100628. Available online: (Accessed 22 July 2020).

Moovit, 2020. Impact of coronavirus (COVID-19) on public transit usage. Available online: https://moovitapp.com/insights/en/Moovit_Insights_Public_Transit_Index-countries. (Accessed 20 July 2020).

Nyhan, M., Grauwin, S., Britter, R., Misstear, B., McNabola, A., Laden, F., Barrett, S.R.H., Ratti, C., 2016. "Exposure track" the impact of mobile-device-based mobility patterns on quantifying population exposure to air pollution". Environ. Sci. Technol. 50, 9671–9681. Available online: https://pubs.acs.org/doi/pdf/10.1021/acs.est.6b02385. (Accessed 31 July 2020).

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. Available online: https://www.R-project.org/.

Organisation for Economic Co-operation and Development (OECD), 2019. Functional urban areas in Spain. Available online: http://www.oecd.org/cfe/regionaldevelopment/Spain.pdf. (Accessed July 2020).

Picardo Costales, L., 2018. Dime dónde vives pero no sabré quién eres. Nuevas dinámicas en la distribución socio-espacial. El caso de Madrid entre 2001 y 2011, N13, pp. 79–100. https://doi.org/10.20868/tf.2018.13.3805. Available online: (Accessed 30 September 2020).

Pontes, J., 2020. Madrid a Dos Velocidades: Sureste Metropolitano vs Noroeste Residencial. El Confidencial. Article (in press): https://www.nuevatribuna.es/articulo/actualidad/estudio-sociologico-desigualdad-comunidadmadrid-sureste-noreste/20200505081326174443.html. (Accessed 20 August 2020).

Pullano, G., Valdano, E., Rubrichi, S., Colizza, V., 2020. Evaluating the effect of demographic factors, socioeconomic factors, and risk aversion on mobility during the COVID-19 epidemic in France under lockdown: a population-based study. The Lanced Digital Health 2 (12), 638–649.

Quealy, K., 2020. The Richest Neighbourhoods Emptied Out Most as Coronavirus Hit New York City. May 15. The New York Times. Available online: https://www.nytimes.com/interactive/2020/05/15/upshot/who-left-new-york-coronavirus.html. (Accessed 22 July 2020).

Rubiales Pérez, M., 2016. Territorio y crisis: impacto territorial de la crisis económica en las regiones metropolitanas de Madrid y Barcelona. Scripta Nova 20. https://doi.org/10.1344/sn2016.20.17208. Available online: (Accessed 29 September 2020).

Sánchez, C., 2020. El virus deja sin ingresos a 2 millones de trabajadores que operan en negro. El Confidencial. April. Available online: https://www.elconfidencial.com/economia/2020-04-05/economia-sumergida-coronavirus-pandemia-negro-hosteleria_2534287/. (Accessed 24 July 2020).

Schneider, D., Harknett, K., 2020. Essential and vulnerable: service-sector workers and paid sick leave. SHIFT report. Available online: https://shift.hks.harvard.edu/files/2020/04/Essential_and_Vulnerable_Service_Sector_Workers_and_Paid_Sick_Leave.pdf. (Accessed 19 July 2020).

Shadmi, E., Chen, Y., Dourado, I., et al., 2020. Health Equity and COVID-19: global perspectives. Int. J. Equity Health 19 (104), 1–16. Available online: https://link.springer.com/content/pdf/10.1186/s12939-020-01218-z.pdf. (Accessed 9 September 2020).

Spain Orden Snd/399, 2020. De 9 de mayo, para la flexibilización de determinadas restricciones de ámbito nacional, establecidas tras la declaración del estado de alarma en aplicación de la fase 1 del Plan para la transición hacia una nueva normalidad. núm 130, 31998. I. https://www.boe.es/boe/dias/2020/05/09/pdfs/BOE-A-2020-4911.pdf.

Spain Orden Snd/414, 2020. De 16 de mayo, para la flexibilización de determinadas restricciones de ámbito nacional, establecidas tras la declaración del estado de alarma en aplicación de la fase 2 del Plan para la transición hacia una nueva normalidad. núm 138, 33312. I. https://www.boe.es/boe/dias/2020/05/16/pdfs/BOE-A-2020-5088.pdf.

Spain Real Decreto 463, 2020. De 14 de marzo, por el que se declara el estado de alarma para la gestión de la situación de crisis sanitaria ocasionada por el COVID-19. núm 3692, 25392. Web: https://www.boe.es/eli/es/rd/2020/03/14/463/dof/spa/pdf.

Spain Real Decreto-ley 10, 2020. De 29 de marzo, por el que se regula un permiso retribuido recuperable para las personas trabajadoras por cuenta ajena que no presten servicios esenciales, con el fin de reducir la movilidad de la población en el contexto de la lucha contra el COVID-19. núm 87, 27629. Web: https://www.boe.es/boe/dias/2020/03/29/pdfs/BOE-A-2020-4166.pdf.

Spain Real Decreto-ley, De 9 de junio, de medidas urgentes de prevención, contención y coordinación para hacer frente a la crisis sanitaria ocasionada por el COVID-19, . 163, sec. I, p. 38723. Web: https://www.boe.es/boe/dias/2020/06/10/pdfs/BOE-A-2020-5895.pdf.

Sy, Karla Therese L, Martinez, Micaela E., Rader, Benjamin, White, Laura F., 2020. Socioeconomic disparities in subway use and COVID-19 outcomes in New York City. Medrxiv. Preprint. Available online: https://doi.org/10.1101/2020.05.28.20115949 (Accessed 21 July 2020).

Tello, J.E., Jones, J., Bonizzato, P., Mazzi, M., Amaddeo, F., 2005. A census-based socio-economic status (SES) index as a tool to examine the relationship between mental health services use and deprivation. Soc. Sci. Med. 61 (10), 2096–2105. https://doi.org/10.1016/j.socscimed.2005.04.018. Available online: (Accessed 3 August 2020).

Trias-Llimós, S., Riffe, T., Bilal, U., 2020. In: Monitoring Life Expectancy Levels during the COVID-19 Pandemic: Example of the Unequal Impact in Spanish Regions. MedRXiv (Pre-print). Available online: https://www.medrxiv.org/content/10.1101/2020.06.03.20120972v2.full.pdf. (Accessed 9 September 2020).

Walker, A.E., Becker, N.G., 2005. Health inequalities across socio-economic groups: comparing geographic-area-based and individual-based indicators. Publ. Health 119 (12), 1097–1104. https://doi.org/10.1016/j.puhe.2005.02.008. Available online: (Accessed 3 August 2020).

Weill, J.A., Stigler, M., Deschenes, O., Springborn, M.R., 2020. Social distancing responses to COVID-19 emergency declarations strongly differentiated by income. Proceedings of the National Academy of Sciences 117 (33), 19658–19660.