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# Unveiling the pandemic's impact on visits to Madrid's parks: insights from mobile phone data analysis

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## ABSTRACT

Changes in human mobility due to the COVID-19 pandemic have particularly impacted urban parks, altering their use patterns. The use of Big Data sources enables the quantification and tracking of changes, although few studies delve into their spatial representation and the socio-demographic characterisation of park users. In this research, we use anonymised cellular network-based data with associated user profile information to quantify and map the changes operated in trips to Madrid's urban parks in a week of reference before and after the pandemic. Our results show a general decrease in trips to urban parks, especially by males in all age ranges. We also observe a marked decrease in trips by the high-income population. Finally, we have nicely presented some of these results in a composition of several maps that provide visual insight into the main changes.

## ARTICLE HISTORY

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## KEYWORDS

Urban green infrastructure; urban parks; leisure mobility; cellular network-based data; equity of park access

## 1. Introduction

City dwellers use parks and other open green spaces to fulfil different needs and benefit from multiple ecosystem services (Kabisch et al., 2016). The scientific literature provides evidence on local climate regulation, air cleaning, noise reduction, flood mitigation, biodiversity enhancement, mental restoration, and social interaction (Gómez-Baggethun & Barton, 2013; Maes et al., 2019). It is agreed that direct visits imply more benefits than unintentional contact (Liu et al., 2023). That is why questions such as providing and accessing green spaces become pivotal in urban open space planning (Maruani & Amit-Cohen, 2007). That is also why the effect of the COVID-19 pandemic on the use of urban parks has been the focus of interest of recent literature (Gao et al., 2023; Jay et al., 2022; Kim et al., 2023; Larson et al., 2021; Sung et al., 2022; Ugolini et al., 2021; Venter et al., 2020; Zhang & Li, 2023). Social distancing was the critical measure to reduce transmission, and most countries agreed upon specific recommendations and mobility restrictions (López & Rodó, 2020). Consequently, the pandemic significantly changed human mobility patterns in general, especially leisure mobility (Östh et al., 2023).

The studies on park-related mobility during the pandemic and post-pandemic have provided varied results concerning use patterns, depending on particular contexts in the disease prevalence and impact, on specific government strategies (Larson et al., 2021),

and on the characteristics of parks (Lu et al., 2021) and their surroundings (Zhang & Li, 2023). These studies have mainly focused on quantifying changes such as the number and frequency of visits, time spent in parks, and distances travelled.

The information to assess those changes may come from different sources. Although traditional methods exist (questionnaires and interviews), they require much time and dedication (Liu et al., 2023), resulting in high costs. Over the last few years, the use of geolocated data from sensors and devices has proved to help monitor the movement of the population across space and time (García-Palomares et al., 2018) and also in the case of green spaces (Heikinheimo et al., 2020). According to Guo et al. (2022), big data-based research applied to urban parks is still scarce but showing a significant increase since 2017 and later, especially with the pandemic (Guo et al., 2022; Kim et al., 2023). Among the different mobile phone data sources used for behaviour research (Wang et al., 2018), smartphone sensor-based data coming from public applications are the most used, as in Curtis et al. (2022), Gao et al. (2023), Jay et al. (2022), Kim et al. (2023), Lu et al. (2021), Venter et al. (2021). Although less frequently reported in the literature, cellular network-based data have also proved useful in studying urban park use in the pandemic context, as in Östh et al. (2023), Sung et al. (2022), and Zhang and Li (2023).

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In this work, we use mobile phone data to study the impact of COVID-19 on the mobility associated with ten urban parks in Madrid. The novelty in our contribution is fourfold: We use cellular network-based data aggregated at the transport zone level; in the origin-destination matrices, destinations are transport zones that coincide with urban parks; the mobile phone data used in this research include anonymised socio-demographic and socio-economic information; beyond quantifying mobility changes concerning urban parks, we show the changes spatially explicit through maps.

In the remaining sections, we present an overview of the study area, a description of the data, and an outline of the research method. Then, we analyse the patterns of park visits, explore the demographics and timing of park use, and present the results through a central map. Lastly, we conclude by summarising the key insights derived from the study and addressing limitations.

## 2. Study area

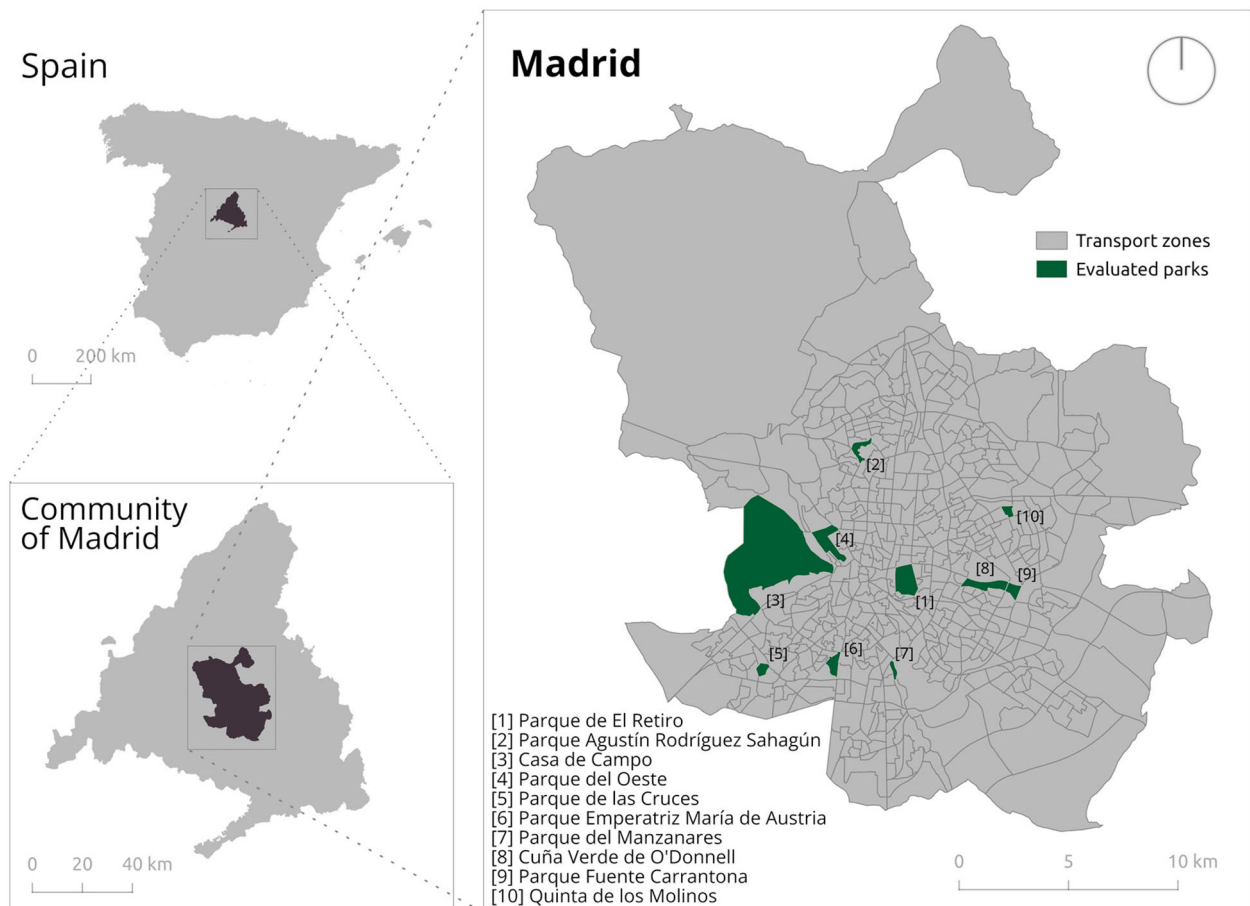
The municipality of Madrid is located in the Meseta Central of the Iberian Peninsula (Figure 1). It belongs to a climatic transition zone between Mediterranean

**Table 1.** Description of the selected parks.

Transport zone ID	Park Name	Size (Ha)	Since
079-03-047	Parque de El Retiro	117	1868
079-06-104	Parque Agustín Rodríguez Sahagún	18	1995
079-09-223	Casa de Campo	1,536	1931
079-09-226	Parque del Oeste	79	1905
079-10-248	Parque de las Cruces	45	1980
079-11-297	Parque Emperatriz María de Austria	60	ND
079-12-330	Parque del Manzanares	45	2003
079-14-377	Cuña verde de O'Donnell	41	2006
079-14-378	Parque Fuente Carrantona	23	2010
079-20-543	Quinta de los Molinos	21	1982

and cold semi-arid climates, which plays a significant role in shaping outdoor activities, including park visits. Madrid experiences hot summers (around 25°C on average) and relatively mild winters (around 8°C on average) (AEMET, 2023). According to the most recent municipal census (Ayuntamiento de Madrid, 2023a), the population stands at 3.3 million inhabitants, with females accounting for 53.3% and males 46.7%. Regarding age distribution, 66.2% of the population falls within the 16–64-year range, 20.3% are aged 65 and above, and 13.6% are below the age of 16.

Madrid is a highly sought-after tourist destination, attracting millions annually, and the city's cultural riches, prominent landmarks, sports stadiums and lively festivals draw tourists worldwide (García-Palomares et al., 2015).



**Figure 1.** Study area and location of the selected parks.

Madrid has over 6,000 hectares dedicated to green spaces, distributed among over 200 parks, forest parks and historical parks (Ayuntamiento de Madrid, 2023b). To ensure the precision and relevance of our research, we have selected ten parks (Figure 1 and Table 1) that coincide with some of Madrid's transport zones.

### 3. Data and methods

#### 3.1. Data

We use origin-destination matrices coming from anonymised cellular network-based data for a research period of two weeks: 14–20th of February 2020 and 13–19th February 2022. The solution Mobility Insights produces these matrices as the result of the agreement between the company Nommon and the mobile network operator Orange España, which operates a market share of over 20% in Spain (Burrieza-Galán et al., 2022; Nommon, 2023). That volume of users is considered a representative sample, apart from children and elderly to a lesser extent. This sample is used to raise the dataset for the entire object population through the municipal census. The solution Mobility Insights processes geo-located and anonymised cellular network-based data generated from mobile phone interactions with the network operator, using active interactions (like voice calls or internet usage) and passive events (like changes in the coverage antenna or running apps) (Burrieza-Galán et al., 2022). These interactions (with a minimum frequency of 30 min) offer the users' approximate position, refined using a probabilistic algorithm based on land use information. That method assigns users to different transport zones, enabling the construction of origin-destination matrices (Burrieza-Galán et al., 2022).

A record from an origin-destination matrix shows all trips registered in one hour between two different transport zones among the existing 1,171 zones in the Madrid region, together with an estimation of the global travelled distances in Km. Every record includes fields for date, hour period (from PH00 to PH23), transport zone codes where trips start and finish, users' country, postal code (in the case of Spanish users), and the income level divided into four groups (I0 is less than 7,000€ per year; I1 is less than 10,000€; I2 is less than 12,000€; I3 is less than 15,000€; and I4 is 15,000€ or more), based on the medium income associated to each residence census tract. Age and gender information appear aggregated into four groups (0–25, 25–45, 45–65, and 65–100 years old), and it is provided by the mobile network operator and is only available for national residents.

Since we are dealing with parks as outdoor recreation places, we can state that, on average, the weather was similar during the two weeks considered in this research. In addition, we have checked that there were no mass events in Madrid during this period, nor were there any special events in the selected parks.

#### 3.2. Methodology

In the first step, we process CSV files containing the mobile phone data and store them in a PostgreSQL database using Python. This database allows us to utilise the spatial database extender called PostGIS for location-based queries. Then we narrow the origin-destination matrices to: (a) the specific periods under examination, then including only the transport zones associated with the municipality of Madrid (584 in total); and (b) the parks (as destinations) that coincide with transportation zones.

Next, we analyse the mobile phone data in two distinct ways: at the park and at the flow level. At the park level, we aggregate the matrices based on socio-demographic and socio-economic characteristics, allowing us to examine patterns concerning who uses these parks and when. At the flow level, we generate flow lines that connect the origins and destinations, considering the centroids of the transport zones. These flow lines provide valuable insight into the spatial dynamics of the area.

Furthermore, we analyse the changes in flow patterns between the pre-pandemic and post-pandemic periods to assess the pandemic's impact on people's visits to parks.

To visually represent the spatial dynamics before and after the pandemic, we created a Main Map. Each park's flows are illustrated separately and in a standardised manner, facilitating comparison between them. This visualisation aids in understanding the alterations in spatial patterns and the impact of the pandemic on the origins and destinations of these flows. Similarly, the Main Map compares the average distance visitors travelled to each park in the pre-pandemic and post-pandemic periods.

### 4. Results and main map

The first result to note is the total number of trips to the selected parks, which has decreased from 1,302,867 trips for the week of 14–20th February 2020 to 1,016,265 trips for the week of 13–19th February 2022. The Main Map and other figures and charts in this section attempt to characterise that change.

Figure 2 shows that *Parque de El Retiro*, *Casa de Campo* and *Parque del Oeste* are the most visited parks, both before and after the pandemic, with a

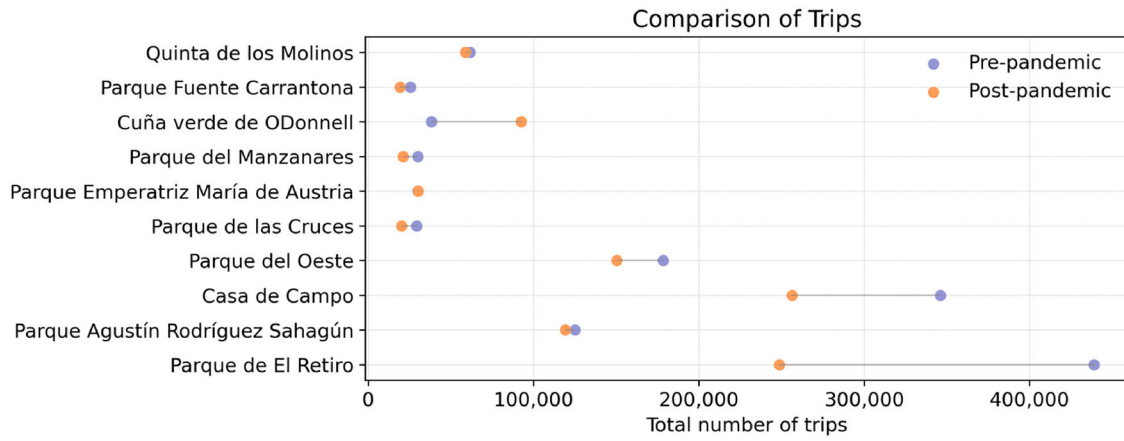


Figure 2. Changes in trips by parks.

percentage of pre-pandemic trips of 33.7%, 26.6%, and 13.7%, respectively. After the pandemic, there has been a considerable decline in visits to all selected parks, except for the *Cuña Verde de O'Donnell*, which experienced a 41% increase in trips. The loss of trips in the case of *Parque de El Retiro* was particularly notable, reaching 43.4%.

Exploring the flow of trips before and after the pandemic for all the selected parks (Figure 3), we see that most trips originate from nearby transport areas.

We can observe the changing flows for each park on the ten partial maps of the Main Map. It is worth

noting that some transport zones close to some parks are no longer origin points for trips (e.g. *Parque de El Retiro* and *Casa de Campo*). For *Parque del Oeste*, most trip losses occurred from nearby transport zones. In the case of *Parque de El Retiro*, trip losses occur not only from the nearest transport zones but also from other more distant transport zones, such as Barajas Airport in the northeast. It is worth noting that *Casa de Campo* exhibits a flow line with a significant loss of trips originating from a distant location. However, this may be caused by the large size of the transport area in the north of Madrid, which results in a centroid

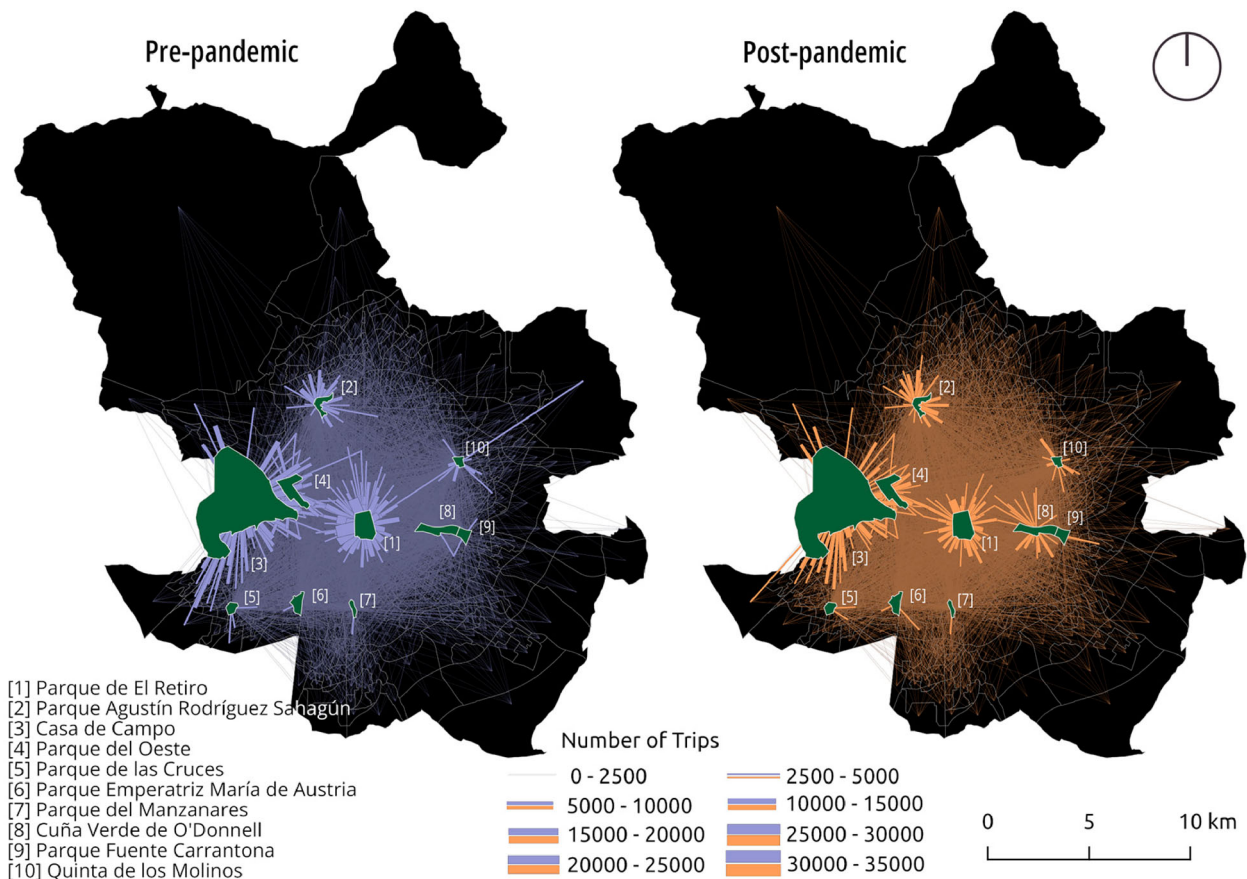


Figure 3. Flows of trips to parks pre and post-pandemic.

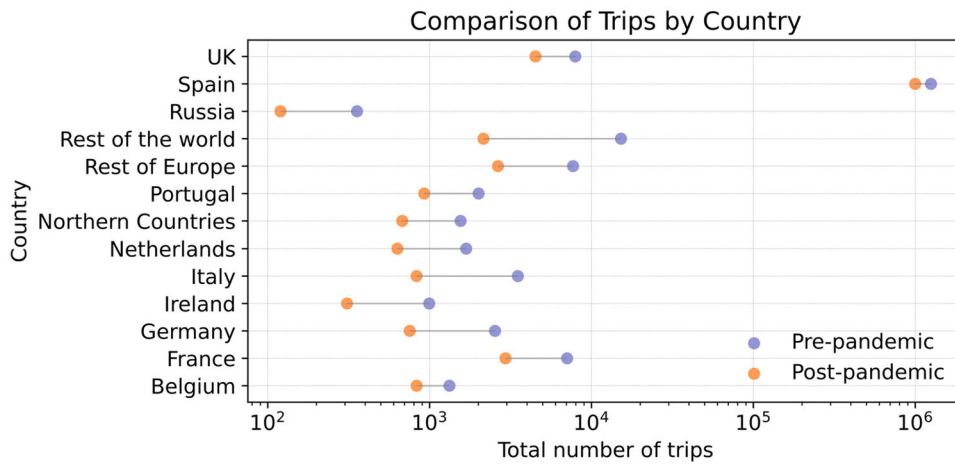


Figure 4. Changes in trips by visitors' country.

far away from *Casa de Campo*. Again, *Cuña Verde de O'Donnell* is a particular case since the trip increase after the pandemic comes especially from close transport zones.

Another interesting aspect is the average distance visitors travel to access parks. The Main Map shows that visitors cover greater distances to reach *Casa de Campo*, *Parque del Oeste*, *Parque del Manzanares*, and *Cuña Verde de O'Donnell*. It is striking that *Parque de El Retiro* has lower coverage than other smaller parks despite being one of the largest spaces. Analysing the changes globally, we observe a decrease in the average distance between the pre and post-pandemic situation, indicating a loss in the coverage of parks. This loss differs among parks, ranging from 80 m (*Parque Agustín Rodríguez Sahagún*) to almost 300 m (*Parque Fuente Carrantona*).

Concerning the temporal patterns (see Main Map), we observe that park visits remain stable throughout the weekdays and decrease at weekends. Regarding the pattern of visits throughout the day, two peaks in visits to parks are evident: a first peak at 7am and a second peak at 2pm. Despite the trip

decrease, both patterns have been maintained after the pandemic.

Since the mobile phone data used in this study is associated with aggregated and anonymised socio-demographic data, we can present some interesting facts. Figure 4 shows how visits by the Spanish population have experienced a relatively minor decrease compared to visitors from various other countries, with a notable decline in visits by Italian or German tourists.

Upon examining the profile of park visitors (Figure 5), it becomes apparent that there is a higher representation of women across most age groups, except for the 0–25 age range, where male visitors outnumber females. However, this demographic pattern shifted following the pandemic, as there was a substantial reduction in male visitors. In contrast, the decline among female visitors is less pronounced. Examining these findings in light of the male-to-female ratio, we observe (Figure 5) that in the pre-pandemic period, the proportion of park visits between men and women closely mirrors the overall gender ratio in the population of Madrid. However, this ratio becomes unbalanced in the post-pandemic period, with the

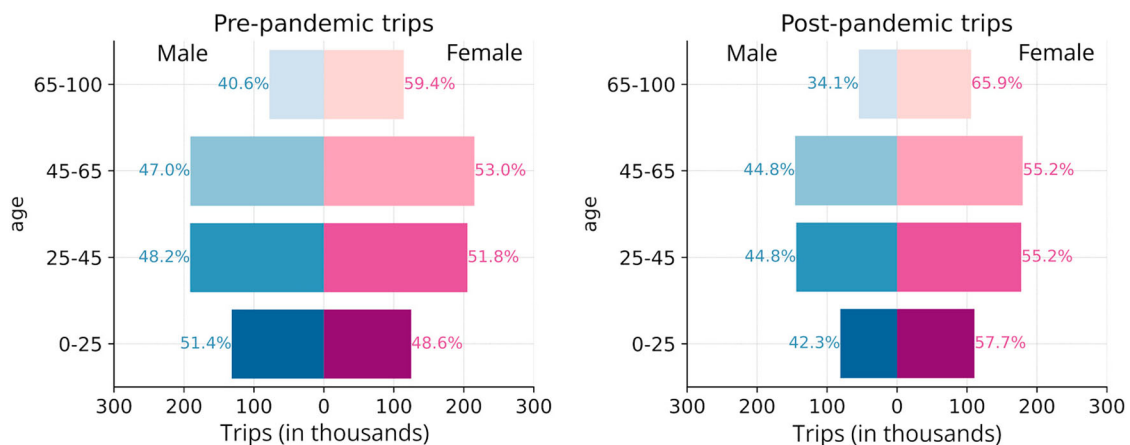
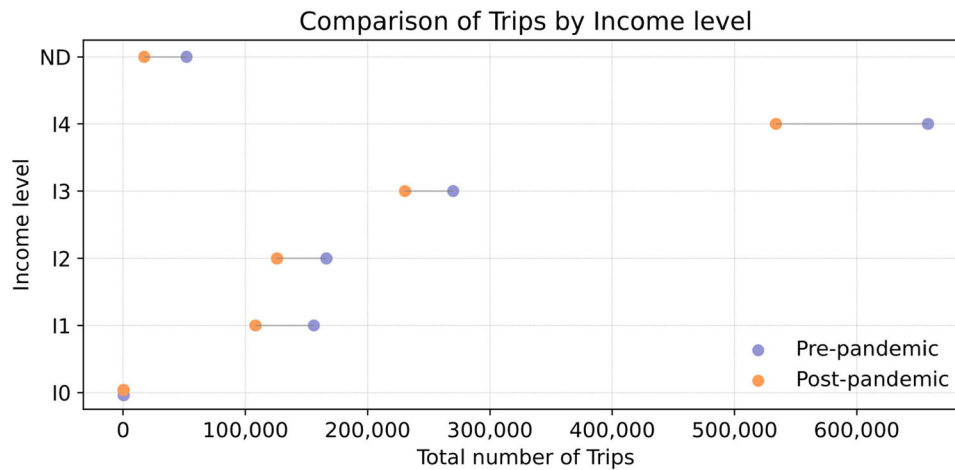


Figure 5. Changes in socio-demographic characteristics of visitors.



**Figure 6.** Changes in socio-economic characteristics of visitors.

number of visits made by men decreasing more than those made by women.

Finally, concerning the income level of park visitors, Figure 6 shows a relationship between the number of trips and socio-economic status. According to the income level of visitors, this distribution of trips changed after the pandemic, with a marked decrease in trips to parks by the high-income population.

## 5. Discussion and conclusions

This article provides a Main Map that shows the changes in trips to Madrid's parks using anonymised cellular network-based data in a week of reference before and after the pandemic.

The results show a general decrease in park visits after the pandemic, which seems to have also happened in other cities, as evidenced by Kim et al. (2023). Parks with more historical and tourist significance, like *Parque de El Retiro* or *Casa de Campo*, experienced a more significant reduction, likely due to a decrease in foreign visitors. Parks with a more local and community-focused character suffered a minor impact, even showing an increase in the number of trips, as in *Cuña Verde de O'Donnell*.

A decrease in the average distance can be observed between the pre and post-pandemic situations, ranging from 80 to 300 m. We have found that although historical and cultural parks generally have more extensive coverage (service areas) (Guo et al., 2019), *Parque de El Retiro* has lower coverage even than other smaller parks. Further research should be done to try to explain this fact.

The findings indicate that trips to parks decrease at weekends (in both pre and post-pandemic situations), which is a general trend also detected by Lin et al. (2021). Concerning the daily pattern, two peaks of trips appear between 7–8am and 2–3pm, coinciding with outdoor sporting activities and lunchtime, respectively.

Since our data includes socio-demographic information, which is uncommon in mobile phone data (Osorio Arjona et al., 2023), we can provide some particular facts in this study. The male-to-female ratio becomes unbalanced in the post-pandemic period, with the number of visits made by men decreasing more than those made by women. This circumstance may be related to women's mobility of care (de Madariaga, 2013). With regard to the income level, the results show a marked decrease in trips to parks by the high-income population after the pandemic, which may be due to more opportunities for the wealthy population to visit different or more distant recreation places.

We assume that this study may have limitations that are inherent to the use of big data. Moreover, we have only compared two weeks, which may give a limited picture, but interesting to show the usefulness of this data and the possibilities for the spatial representation of the analysis results.

Despite these limitations, we believe that cellular network-based data is a source of great interest in understanding how much, when and who benefits from access to city parks. These insights are important for urban (open space) planning to take into account, among others, safety and equity issues and the effect of disruptive events on them.

## Software

We used free and open-source software: PostgreSQL 15 and PostGIS (to store and process data and to create OD matrix lines), QGIS 3.32 (to create preliminary maps), and Inkscape 1.1 (to produce the final map).

## Acknowledgements

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## Data availability statement

Transport zones shapefile is available in the following website: <https://gestiona.comunidad.madrid/nomecalles/DescargaBDTCorte.icm>

Mobile phone data that support the findings of this study are available from the corresponding author, RTG, upon reasonable request.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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