GeoHealth

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Special Section:
The COVID-19 pandemic: linking health, society and environment

Key Points:

- The COVID-19 pandemic in Palma had a concentrated pattern in the peripheral neighborhoods of the eastern part of the city
- Gini index confirms the geographical imbalances in the distribution of the infection, specially in the first waves of the pandemia
- Household characteristics (average income, percentage of single-person, percentage of children under 18 years, average size) explain spatial COVID-19 pattern

Supporting Information:

Supporting Information may be found in the online version of this article.

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Geographical Distribution and Social Justice of the COVID-19 Pandemic: The Case of Palma (Balearic Islands)

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Abstract The spatial distribution of the COVID-19 infection rate in the city of Palma (Balearic Islands) is analyzed from the geolocation of positive cases by census tract and its relationship with socioeconomic variables is evaluated. Data on infections have been provided by the Health Service of the Ministry of Health and Consumption of the Government of the Balearic Islands. The study combines several methods of analysis: spatial autocorrelation, calculation of the Gini index and least squares regression, and weighted geographical regression. The results show that the pandemic comprised five waves in the March 2020–March 2022 period, corresponding to the months of April 2020, August 2020, December 2020, July 2021, and January 2022. Each wave shows a particular geographical distribution pattern, however, the second and third waves show higher levels of spatial concentration. In this sense, the second wave, affecting the peripheral neighborhoods of the eastern part of the city. The Gini index confirms geographical imbalances in the distribution of infections in the first waves of the pandemic. In addition, the regression models indicate that the most significant socioeconomic variables in the prediction of COVID-19 infection are average income, percentage of children under 18 years of age, average size of the household, and percentage of single-person households. The study shows that economic imbalances in the city have had a clear influence on the spatial pattern of pandemic distribution. It shows the need to implement spatial justice policies in income distribution to balance the effects of the pandemic.

Plain Language Summary The article analyses the spatio-temporal pattern of the COVID-19 pandemic in Palma (Mallorca, Balearic Islands, Spain) based on positive case counts. A study is carried out at the census tract level relating the incidence of the pandemic to socio-economic variables. The results show that the incidence of the pandemic has been very unequal at the geographical level. Neighborhoods in the eastern periphery of the city have been the most affected. These areas also concentrate low income levels, small dwellings and households with large numbers of members. Concentration indices confirm these imbalances. The second wave of infection is the one that shows the clearest pattern of concentration of cases. The lack of spatial justice and the contrasts between the west (rich) and east (poor) of the city are revealed.

1. Introduction

The scientific literature confirms that the state of health of people can be influenced by their socioeconomic status (Domínguez-Berjón et al., 2008; Duque et al., 2021; Singer et al., 2017). Therefore, the hypothesis that the number of infections or mortality from COVID-19 could be higher in disadvantaged populations is reasonable (Oronce et al., 2020; Sepulveda & Brooker, 2021). In this sense, the study of the relationships between socio-economic aspects and the degree of infection or mortality from COVID is a topic of interest for the academic community. Therefore, it has been found that the infection and mortality rates of the SARS-CoV-2 virus show diverse spatio-temporal patterns in which the socioeconomic configuration of the affected territories plays a prominent role (Baena-Diéz et al., 2020; Marí-Dell'olmo et al., 2021; Martins-Filho et al., 2021).

In this work, we will delve into the analysis of spatial justice and social equity in relation to the spatio-temporal distribution of COVID-19 cases. Spatial justice refers to the equitable distribution in the geographical space of socially valued resources, to the opportunities to use socially valued resources, and to the balanced distribution of negative or positive environmental, social, or economic externalities (Solly, 2020). Soja (2010) pointed out that spatial justice is constructed through the association between justice and the equitable distribution of social goods in space to offer equal conditions and services for all individuals.

Some authors suggest that the concept of spatial justice should necessarily be incorporated into the field of health to try to improve the health of the population (Baciu et al., 2021). Spatial justice is related to both the way territories face the pandemic and the typology and intensity of its effects on the population. Spatial justice in relation to the COVID pandemic manifests multiple dimensions, including health, economic, environmental, governance, etc. Likewise, it can also be focused on various geographical scales (global, continental, national, regional, or local, etc.).

COVID-19 has shown that it is not socially neutral; it generates and accentuates preexisting inequalities in territories (Buffel et al., 2020). In fact, the communities with the greatest deprivation have also been those that have experienced the greatest impact of the pandemic. Therefore, COVID-19 has deepened and amplified spatial injustice. In fact, COVID-19 has mainly affected disadvantaged groups and has exacerbated the inequities derived from race, age, ethnicity, gender, and disability (United Nations, 2020). It has also exacerbated social stigma and discrimination against ethnic groups (Hoover & Lim, 2021) (WHO, 2020).

The COVID-19 health emergency has shown the great economic, social and environmental vulnerability of urban environments, leading to situations of imbalance or inequity in access to health resources and in terms of the effects of the pandemic. There are several references to the lack of spatial justice caused by COVID-19 in various areas: Africa (Kihato & Landau, 2020), South America, and India (Landy et al., 2021).

In this work, the following hypothesis is proposed: The COVID-19 pandemic has more deeply affected the most impoverished and vulnerable social groups, leaving a polarized territorial pattern and leading to a health gap that has further deepened economic and social imbalances in cities. The objective of this study is to evaluate the geographical and temporal distribution of COVID-19 infection cases in Palma (Balearic Islands, Spain) during the period March 2020–2022 and to analyze its relationship with socioeconomic aspects of the population. The study applies various spatial autocorrelation analysis techniques to detect spatial patterns of pandemic and to relate these with the existing socioeconomical spatial patterns. The results are intended to provide a view of the behavior of the pandemic in an urban Mediterranean island environment and to build a knowledge base that could be useful to face the new stages of this pandemic and develop appropriate mitigation and recovery actions.

The scientific literature includes various references for the analysis of the COVID-19 pandemic in Spain. The work of Miramontes & Balsa-Barreiro (2021) demonstrated that a high spatial resolution analysis helps the management of the pandemic in the region of Galicia (Spain). He notes that the highest number of cases occurred in urban areas and their areas of influence. In addition, he comments that the pandemic arrived somewhat later in Galicia and that its incidence was lower. De Cos Guerra et al. (2021) analyze socio-spatial patterns of the pandemic in the city of Santander (Cantabria, Spain). The study identifies patterns of concentration of positive cases in buildings with neighborhoods with residential function and economic activities. Andrés López et al. (2021) analyze the COVID distribution in the region of Castilla y León (Spain) and show a lower impact of the disease in rural areas and a high concentration in urban centers. Fernández García et al. (2021) evaluate the temporal and territorial dimension of the pandemic in Asturias (Spain). They find that the concentration of the population in urban areas increased the number of cases. Roselló et al. (2021) develop a detailed spatio-temporal study of the distribution of the pandemic in the city of Malaga. They identify points of maximum risk coinciding with areas of maximum human traffic. Aguilar-Palacio et al. (2021) assess inequalities in relation to COVID-19 infections in the Aragon region. They find that low-wage employees living in deprived areas are most affected. Gullón et al. (2022) show a relationship between high deprivation areas and COVID incidence for the first waves for the city of Madrid. The differences are explained by regional pandemic management policies. Also in the city of Madrid, Hierro and Maza (2022) confirm the role of inter-municipal mobility and population density as key factors of contagion. Rojas-Quiroz and Marmolejo-Duarte (2022) show that initially infections were concentrated in high-income areas, but later the pattern shifted toward areas characterized by overcrowding, with more people not having the opportunity to telework, as well as nursing homes. Population density did not prove to be a decisive factor in explaining infection rates.

There are also general studies that analyze the effect of the pandemic in Spain, such as the COVID-19 atlas of the National Geographic Institute (IGN, 2021). At the national level, the work of Paez et al. (2021) shows that the incidence of COVID is lower in areas exposed to high temperatures and high humidity. However, solar exposure seems to play a positive role.

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However, the spatial analysis of the pandemic in the Spanish region of the Balearic Islands has been scarcely addressed. Specifically, to date, the analysis of the spatial pattern of infection rates and its relationship with social aspects in the city of Palma, the capital of the Balearic Islands (Spain), has not been evaluated.

1.1. Case Study

The study of epidemic outbreaks in confined environments helps in the analysis of the effect of isolation intervention strategies, such as quarantine or other mitigation actions. In this sense, island environments are usually chosen as confinement laboratories for the study of diseases. Therefore, the city of Palma (Balearic Islands, Spain) is a suitable geographical area for the epidemiological study of the geographical distribution of those infected with COVID-19. Palma is the capital of the island of Mallorca, the largest island of the Balearic Islands archipelago.

Palma has an area of approximately 208 km^2 and a total of 419,366 inhabitants (IBESTAT, 2021). The city is located in the municipality of the same name, with an area of 208.63 km^2 (Figure 1). The highest population density is located in the eastern expansion of the municipality. Palma has a total of 252 census tracts that are grouped into 88 neighborhoods that are very diverse in terms of their sociodemographic characteristics. The largest census tracts are located on the periphery of the urban center. They are sparsely populated areas and their use is mostly agricultural. Palma concentrates the majority of the large infrastructures of the Balearic Archipelago and of the island of Mallorca itself. The most important transport infrastructure (airport and port), health infrastructure, commercial equipment, industrial equipment, and educational equipment are located there. In addition, most of the administrative bodies of the Balearic Islands are located in the city. Palma also has extensive tourist facilities in its coastal areas (Playa de Palma to the east and Cala Mayor to the west), including hotels, apartments, and numerous tourist offerings (restaurants, leisure, etc.).

The Spanish Government declared a state of alarm throughout Spain on 17 March 2020 to address the health emergency caused by COVID-19 (BOE, 2020). This state of alarm was extended until 21 June 2020. Workers in non-essential services were obliged to stay at home between 30 March and 9 April 2020. Subsequently, on 28 April, the government announced a transition plan toward a new normality that established four emergency phases of the pandemic and divided the country into territorial units. Each unit advanced or retreated independently depending on the dynamics of the pandemic. The Balearic Islands constituted one of these units. At the municipal level, no specific restrictions were established.

The degree of isolation of the city of Palma during the first phases of the pandemic and the declaration of a state of national alarm was extreme. Double isolation was maintained in the city, one normative emanating from the law and another geographical emanating due to the insular isolation that limited the mobility of people to the island. In the subsequent phases of the pandemic, Palma progressively lost its confinement due to the reactivation of tourist activity and the increase in local, insular, and international mobility.

The main economic activity in the city of Mallorca and the Balearic Islands is tourism; therefore, the pandemic has had a direct impact on the productive sector, which is currently having difficulty recovering. Establishing the degree of confinement in the Balearic Islands is the subject of substantial concern because it represents an impact on the arrival of tourists and what this implies. This circumstance has been an added difficulty for the management of the pandemic because the vulnerability of the island is extreme.

The purpose of this study was to provide better knowledge for the management of pandemics in mature tourist destinations. Palma is a city with important social and economic contrasts, and the COVID-19 pandemic highlights its strong socio-urban inequalities (Pérez & Mantiñán, 2020). In Palma, tourism is the engine of the economy, giving rise to great socioeconomic contrasts in which an impoverished society, which works in the tourism sector in low-skilled jobs, and the rich social elite, which leads the tourism and real estate market, coexist.

2. Materials and Methods

2.1. Data Sources

Georeferencing of COVID-19 infections was performed using a process that involved anonymization of health records. This task was carried out thanks to the transfer of the results of the research project “Anonymized Geographic Information System to Support the Fight Against the COVID-19 Pandemic at the Municipal Level”

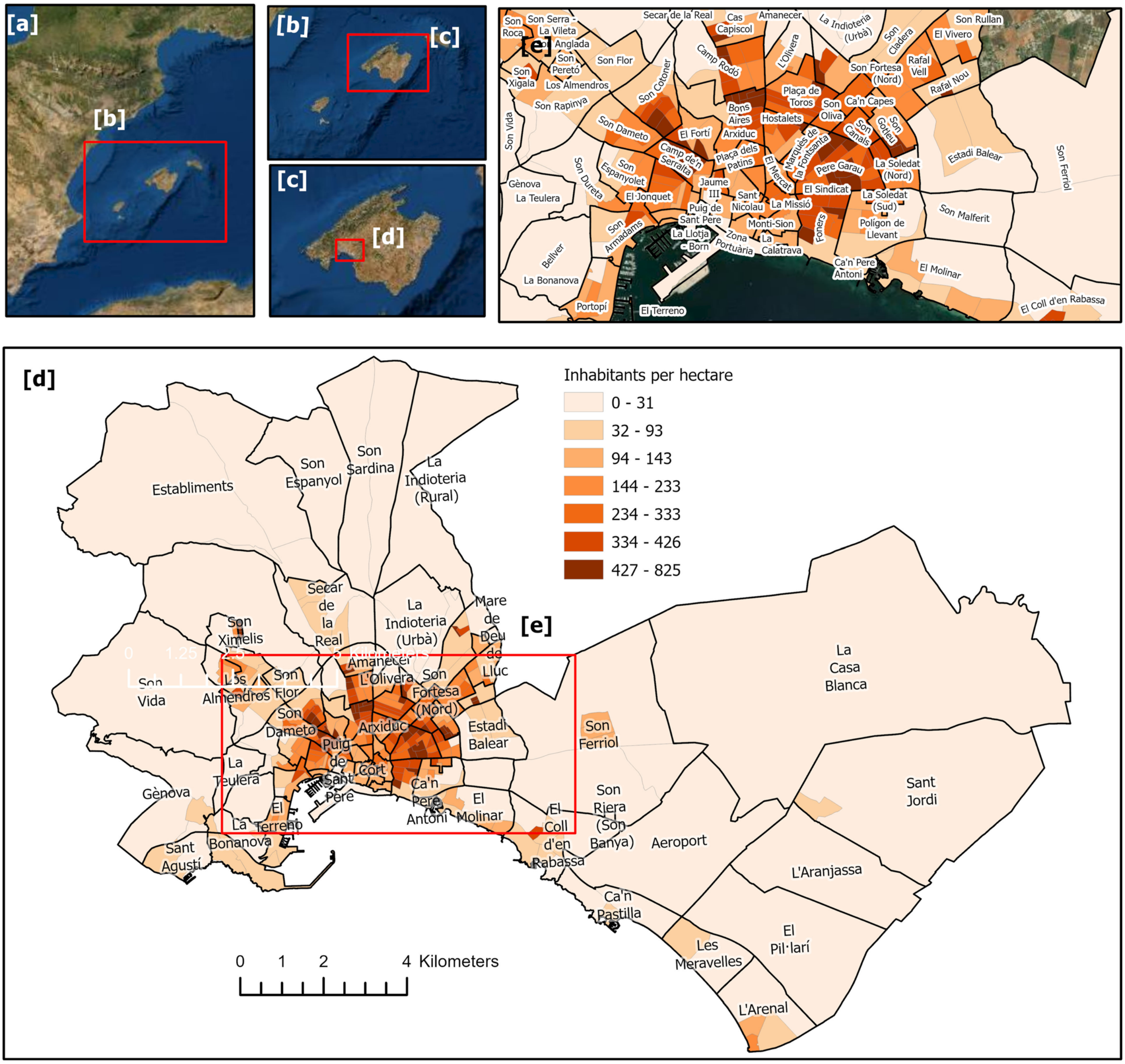

Figure 1. (a) Location of the Balearic Islands in the Western Mediterranean basin (b) Location of Mallorca in the Balearic archipelago (c) Location of Palma on the island of Mallorca (d) Population density in the city of Palma by census tract in 2021 (quintiles) (e) Population density of the center of Palma.

(Ruiz Pérez & Colom Fernández, 2020). This anonymization system eliminates geographical references (postal address or geographical coordinates) in records of individuals with COVID infections and replaces them with a code for the municipality, census section, and neighborhood. The Committee of Research Ethics of the Balearic Islands approved this analysis (IB4200-20 PI) and the anonymization work was carried out by the Platform of Research in Health Information of the Balearic Islands (PRISIB) under the Institut d'Investigació Sanitària de les Illes Balears and the Ministry of Health of the Government of the Balearic Islands.

From the set of information on COVID-19 cases provided by the PRISIB, only positive cases, determined using antigen test and PCR, for the March 2020–March 2022 period were selected. Furthermore, in the event of multiple positive tests for an individual, only the first positive test was included.

To analyze the geographical distribution of the inequalities between the distribution of socioeconomic variables and the number of COVID-19 infections, various indicators collected in the 2018 Household Income Distribution

Table 1
Geographic Information Systems and COVID-19

Reference	Objective
Murugesan et al. (2022)	Maps location-based data and helps epidemiological modeling
Sarwar et al. (2020)	Detect disease in their early stages and simulate spatial-temporal disease.
Ahmadi et al. (2023)	Evaluating the efficiency of relief centers in terms of location.
Dangermond et al. (2020)	Support emergency phases, representing and sharing data, elaborate detailed models of spatial and temporal diffusion.
Rahman, Mahmud, and Rabbi (2021), Kianfar and Mesgari (2022)	Develop of spatial regression models (ordinary least squares, spatial lag model, geographically weighted regression)
Zhou et al. (2020)	GIS & big data integration for epidemiological monitoring and modeling
Nasirzadeh and Sidiqui (2022)	Dynamic scenario modeling
Clin et al. (2020)	Changes in the spatial distribution of COVID-19
De Cos Guerra et al. (2021), Mollalo et al. (2020)	Explore spatial relationship between environmental, socioeconomic and demographic variables and COVID-19.

Atlas prepared by the National Institute of Statistics (Instituto Nacional de Estadística) were used. The following variables were selected: income level (gross and net), unemployment rate, population density, average household size, percentage of young people, percentage of elderly people, and percentage of single-parent households.

2.2. Analysis of the Geographical Distribution and Social Equity of the Pandemic

The use of Geographic Information Systems (GIS) has become widespread in the analysis of COVID-19 (Ahasan et al., 2020). Franch-Pardo et al. (2020) point out that the study of COVID-19 using a GIS provides an interdisciplinary approach with a global perspective and allows spatio-temporal analysis of the pandemic, web mapping or data mining among other functions. There are many references to the use of GIS in pandemic analysis (Table 1).

Therefore, the analysis of the geographical distribution of the COVID-19 pandemic, the spatial statistics functions included in ArcGIS Pro 2.8 and Geoda 1.2 were used (Anselin et al., 2006). Specifically, global spatial autocorrelation and local spatial autocorrelation (LISA) of the disease distribution were evaluated for each wave at the census section level. In addition, two methods of spatial econometric analysis have been used: Lorenz curves and the Gini coefficient. These allow us to identify the level of spatial concentration in the distribution of a resource/property (in our case the number of COVID-19 positives) and to detect inequity in its distribution. Finally, regression models were applied (ordinary least squares and geographic weighted regression) to evaluate the dependence of infection rates on socioeconomic variables. A detailed description of the applied methods can be found in Supporting Information S1.

3. Results and Discussion

The database built of COVID-19 infections in Palma for the March 2020/March 2022 period comprises a total of 85,341 cases. The temporal distribution of COVID-19 infections by month (Figure 2) allows the differentiation of five peaks, herein referred to as waves of infection (Table 2). Importantly, these waves are based exclusively on available empirical data grouped at the monthly level and do not strictly correspond to the waves of the pandemic specified by the health authorities in the Balearic Islands (GOIB, 2022). Therefore, each wave is represented by the months of the year with maximum values. As seen in Figure 1, five waves were identified: April 2020 (first wave), August 2020 (second wave), December 2020 (third wave), July 2021 (fourth wave), and January 2022 (fifth wave).

After the first wave (April 2020), the rest of the waves coincide with the high tourist season (August 2020, July 2021) and post-holiday period of Christmas and the end of the year (December 2021 and January 2022). This could be due to an increase in personal contact that usually occurs in these periods.

The trend of the temporal evolution of the number of infections shows a progressive increase for each of the waves for the time period considered. The first wave corresponds to the month of April 2020 and was the smallest

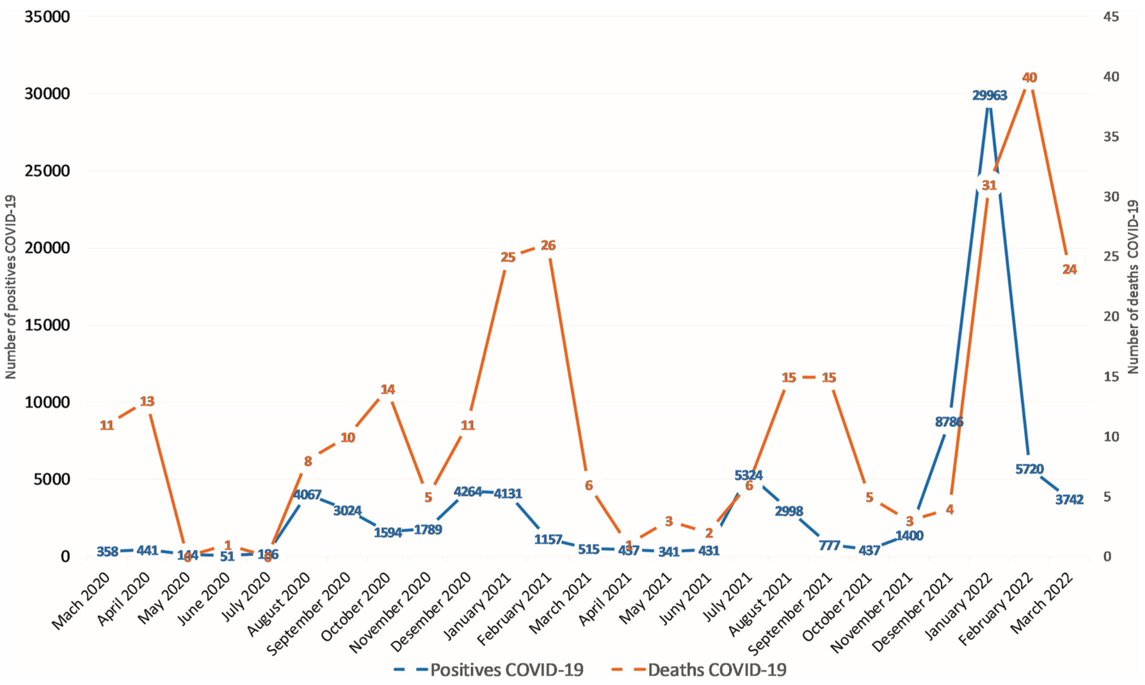

Figure 2. Monthly evolution of positive cases and deaths from COVID-19 in the city of Palma from March 2020 to March 2022.

and coincided with the confinement phase of the state of alarm (441 cases). The last wave of infection evaluated occurs in January 2022 and is when the highest infection rates are recorded (29,963 cases).

The cumulative total of infections and deaths from COVID-19 shows a progressive intensification of the pandemic since its inception. Therefore, there was a constant increase in both the number of infections and the number of deaths (Figure 3). The number of infections grew exponentially, with greater intensity than the number of deaths. These data indicate that the effects of the different variants of COVID-19 on the number of infections have not had the same impact on the number of deaths. The latter variants, although they have been very aggressive in terms of infection, have not entailed a greater risk of mortality.

The number of deaths from COVID-19 shows a different temporal distribution than the number of positives. First, there is a 1-month delay between positives and deaths. In addition, the duration of the waves is usually longer and spans 2 months in some cases (waves 2, 3, and 5), and a greater number of waves can be differentiated. This is mainly due to the number of hospitalizations that increased after the waves of infection, and deaths occurred several weeks after hospital admission.

The geographical distribution of the total COVID-19 positive cases and by wave is presented in Figures 4 and 5. The highest concentration of positives is observed in the eastern periphery of the urban center of the city. The census tracts with agricultural uses on the outskirts of the city are those with the lowest concentration of positives.

The analysis of the level of concentration of cases through the calculation of the Moran global coefficient (Table 2) indicates that the first wave (April 2020) and the last wave (January 2022) show a low level of significance, while the rest of the waves present some clustering. In particular, the highest concentration of cases occurs in the second wave (August 2020), with a Moran index of 0.16.

The mapping of the local Moran index (LISA clusters) shows specific clustering patterns for the different waves of infection (Figure 5) and for the total cases (Figure 4b). In the first wave, there is a specific concentration of cases in census sections in which nursing homes and hospitals are located in the northern part of the urban area of the city (Secar de la Real, Establiments, Les Maravelles). This situation shows the high vulnerability of these groups

Table 2
Spatial Autocorrelation of the Geographical Distribution of COVID-19 Infections by Wave

Wave	Month	Moran's index significant = 0.05	*p* value	*z* score	Gini coefficient
Wave 1	April 2020	−0.01	0.61	−0.50	0.64
Wave 2	August 2020	0.16	0.00	10.55	0.30
Wave 3	December 2020	0.06	0.00	4.13	0.27
Wave 4	July 2021	0.04	0.00	2.87	0.24
Wave 5	January 2022	0.00	0.74	0.32	0.16

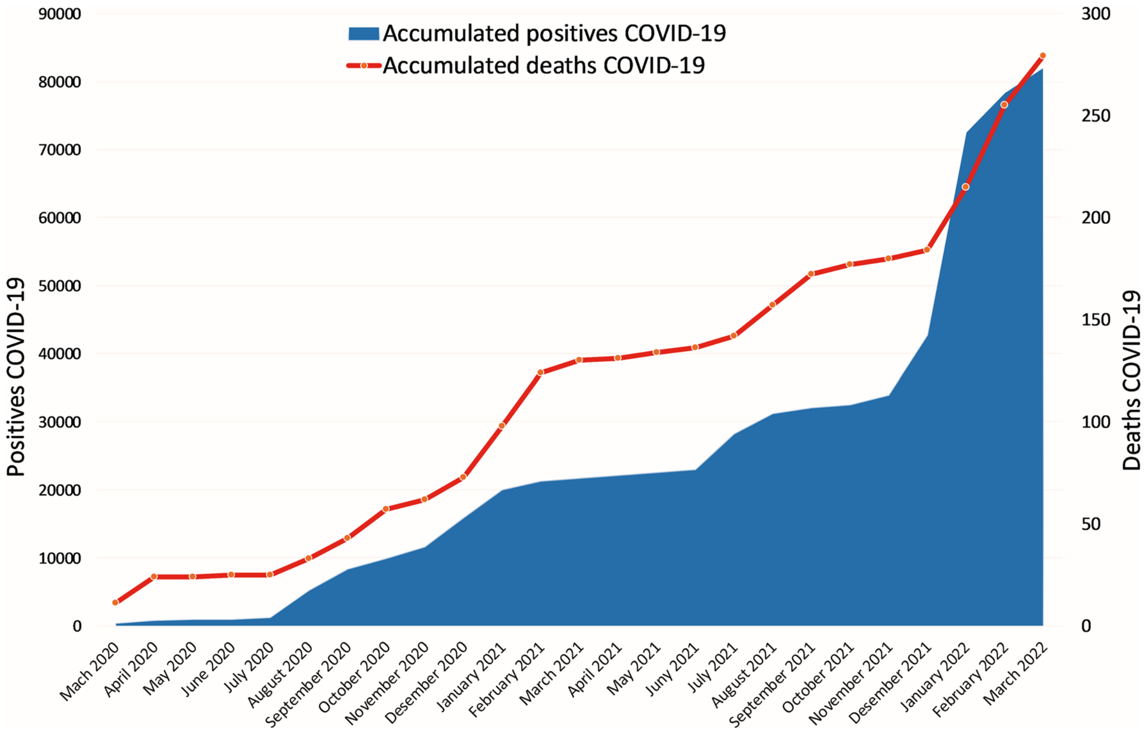

Figure 3. Cumulative total positive cases and number of deaths from COVID-19 in the city of Palma for the March 2020–March 2022 period.

to the pandemic and the importance of the environment in guaranteeing the quality of life of elderly individuals. The grouping of elderly people in nursing homes has led to a concentration of risk in highly sensitive groups.

The geographical distribution of the second wave allows a clear visualization of a bipolar zoning of the city in which the positive cases are mostly grouped in the eastern area of the expansion of the city; in the western area, the lowest values are observed (Estadi Balear, Son Gotleu, Pere Garau, Son Canals, etc.). The third wave repeats a pattern quite similar to the second wave; however, the positive cases extend more through the area of the northern expansion of Palma (La Indioteria). There are also very high values in the Bonanova neighborhood in the southwest of the city. In this case, the infection spreads and affects more peripheral neighborhoods of the northeast area, which have a high population density. The fourth wave is not very significant in terms of its territorial pattern. A specific pattern cannot be detected; it is a pattern of generalized expansion of the pandemic. However, the pattern of the fifth wave is quite similar to that of the third wave.

The global analysis of the distribution of cases for the entire study period (Figure 4b) again shows an important concentration of rates in the peripheral area of the eastern part of the urban case of the city (Estadi Balear, Son Gotleu, Pere Garau, Son Canals, etc.).

The geographical distribution of the socioeconomic variables considered shows a concentrated distribution of poverty and deprivation in the eastern part of the city. This zone concentrates areas with high population densities, low income levels, mostly young populations, households with a greater number of members, fewer single-person households and higher unemployment rates (Figure 6).

The analysis of the global Moran coefficients of the variables considered (Table 3) and the distribution of the LISA outlier clusters (Figure 6) show significant geographic clustering levels for all variables. The value of 0.58 is relevant for the income level, and the percentage of single-person households (0.62) highlights significant levels of concentration.

The geographical distributions of COVID infections seem to be influenced, a priori, by a socioeconomic structure that shows significant imbalances.

Therefore, the distribution of wealth in the city does not maintain the principles of geographical equity and higher rates of infection manifest themselves in disadvantaged sectors.

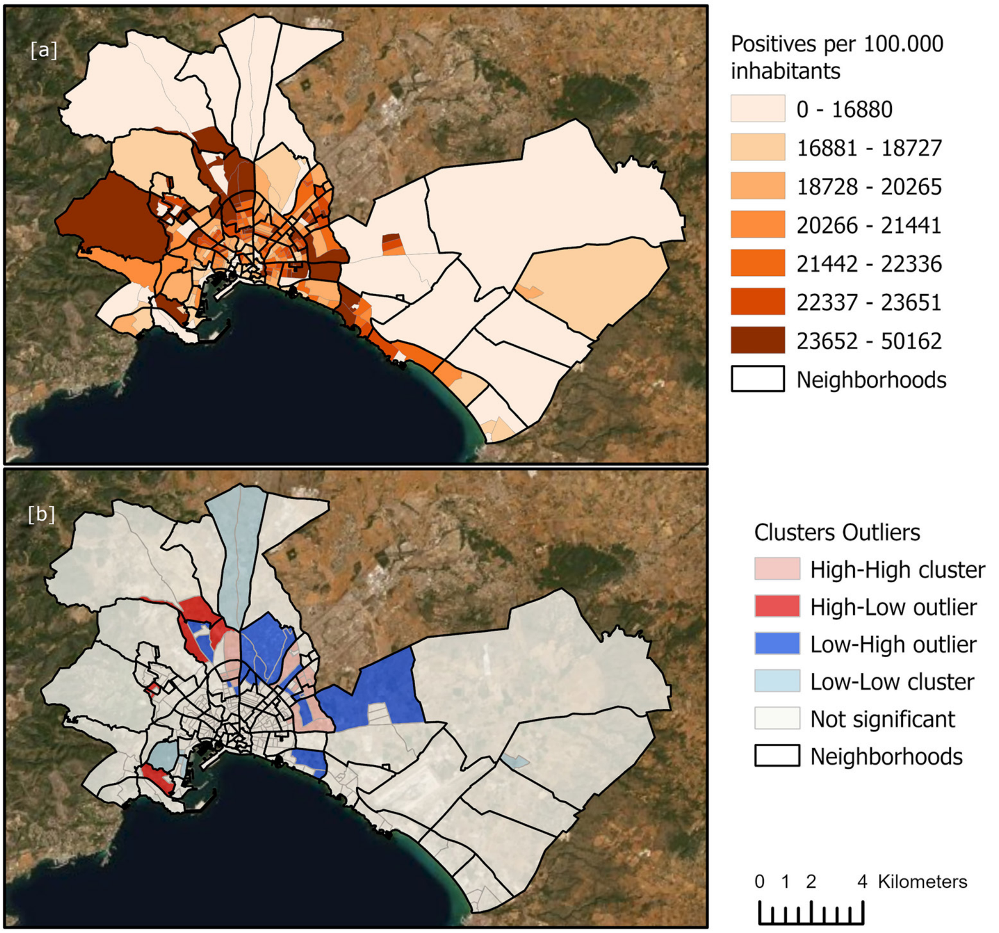

Figure 4. (a) Total geographic distribution of positive cases per 100,000 inhabitants (quartiles), (b) LISA clusters of total cases.

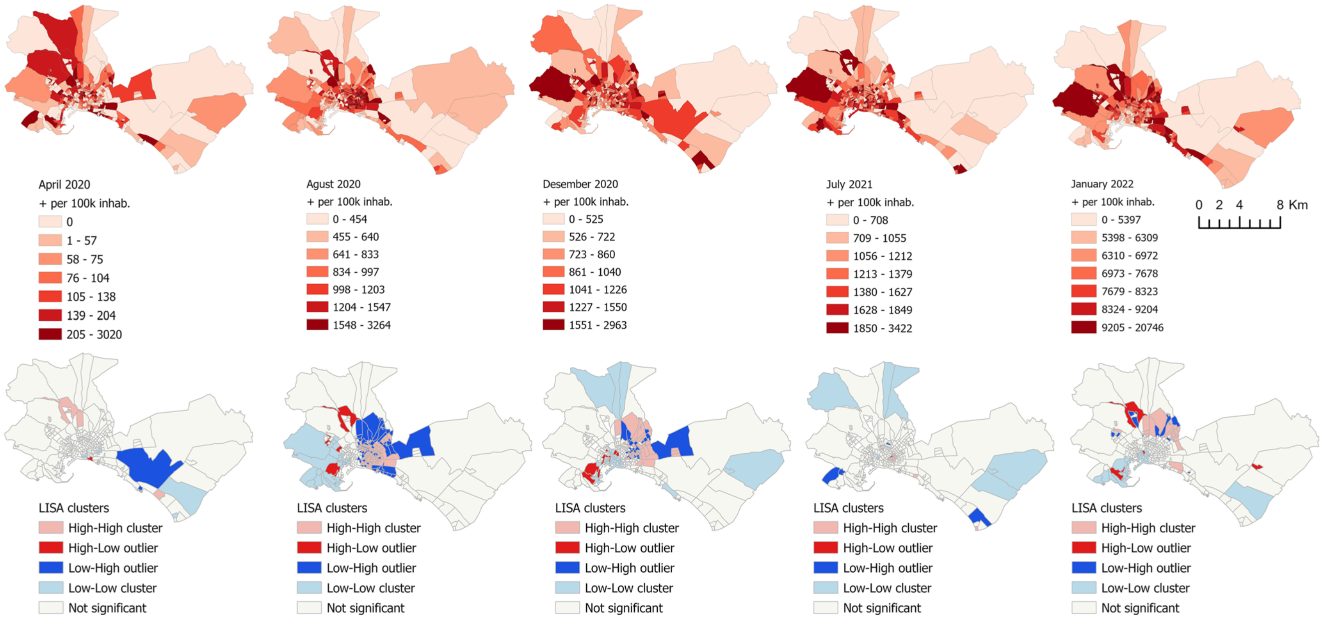

Figure 5. Distribution of COVID-19-positive cases by census tract by wave (quintiles) and LISA clusters.

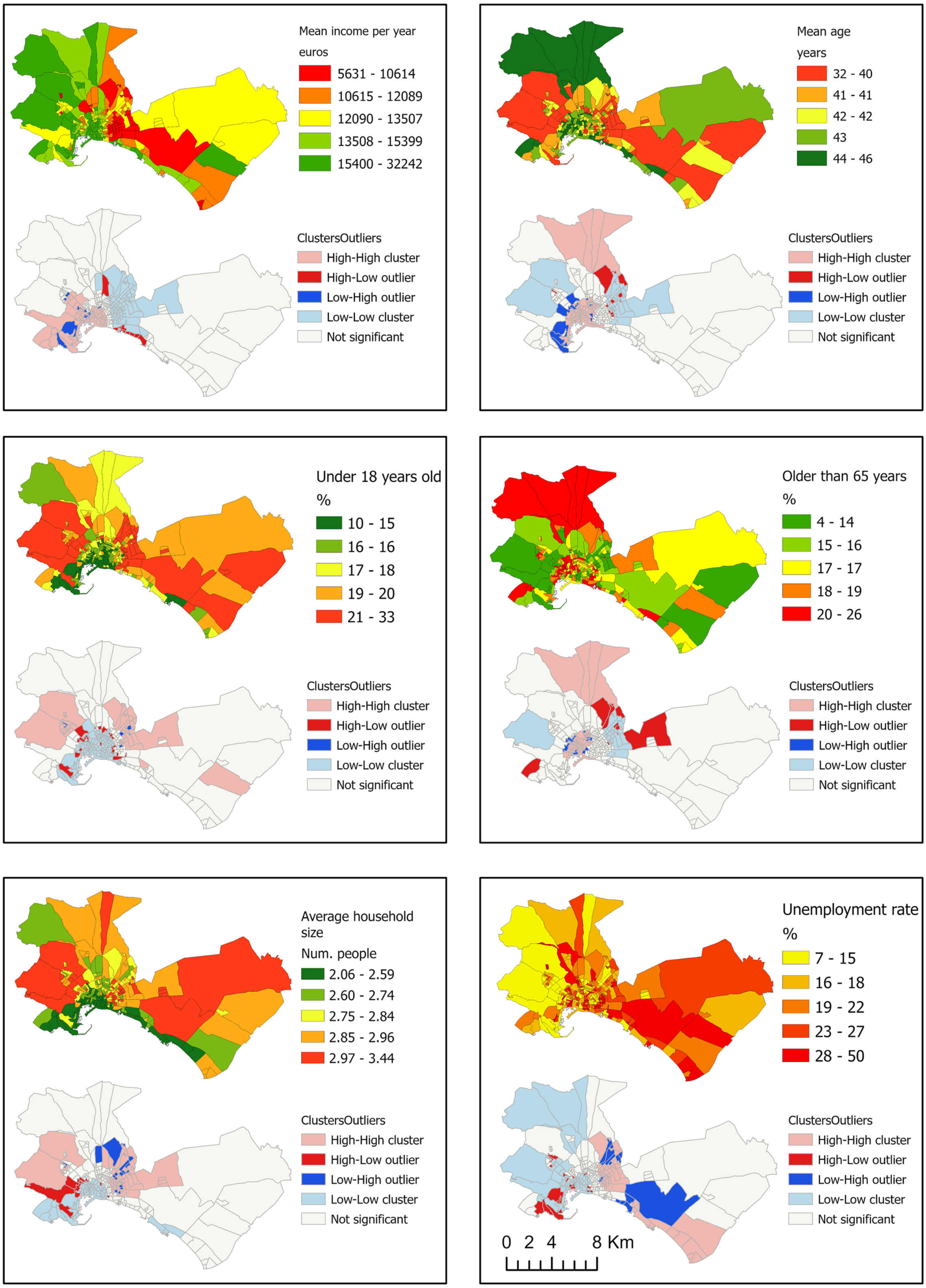

Figure 6. Mapping of socioeconomical variables and its Local Moran's clusters and spatial outliers.

Table 3
Moran's Index of Socioeconomic Variables

Variable	Moran's index significant = 0.05	*p* value	*z* score
Net income	0,587	0.001	15.333
Average age	0.380	0.001	9.758
% under 18 years	0.503	0.001	13.381
% over 65 years	0.322	0.001	8.420
Household size	0.567	0.001	15,623
% Single-person households	0.628	0.001	16.777
Unemployment rate	0.207	0.001	5,601
Population density	0,511	0.001	13.608

The results of the bivariate spatial autocorrelation analysis (Table 4) between the number of COVID-19 infections per wave and the socioeconomic variables considered indicate that the net income variable has the highest coefficients (Wave 2: −0.291, Wave 5: −0.127, Total positives: −0.111, *p*-value = 0.001). Negative coefficients indicate an inverse relationship between income and the COVID-19 positivity rate.

The bivariate Moran indices for average age, under 18 years and over 65 years also show that the effect of the pandemic is more intense in the younger population. However, as references confirm, the prognosis and severity of the disease have always been worse among the elderly population (Cortis, 2020).

The average household size is also a factor that increases COVID-19 cases. In this case, the bivariate Moran coefficients are positive and significant for the second and fifth waves. The greater the number of household members, the lower the degree of isolation, significantly increasing the probability of infection.

The percentage of households with one person exhibits notable behavior. For the second wave, a coefficient of −0.088, *p*-value = 0.001, is obtained, indicating that people who live alone have lower chances of infection. This dynamic is maintained for the fifth wave. However, for the fourth wave, a positive coefficient is obtained for this variable. This finding is difficult to interpret, although its cause could be due to an increase in testing among the population in the fourth wave, potentially skewing the results.

The population density exhibits predictable behavior, with significant coefficients for all waves, except for the first wave, and the signs for each wave are positive. This confirms that the higher the population density in general, the greater the number of cases. This trend contrasts with that described in other studies (No et al., 2020) in which population density has been considered a mediating factor of the pandemic linked to social isolation, but with little relation to the number of cases.

A speculative analysis of the effect of each wave it could be said that COVID-19 infection in its early stages affects the elderly (residential homes), then attacks socially and economically vulnerable young people in the east of the city, then spreads widely in densely populated suburbs of the city, then widely affects all social sectors, and finally schoolchildren have the highest infection rates.

The bivariate local spatial autocorrelation between COVID cases and socioeconomic variables indicates geographical patterns that confirm the global bivariate coefficients. In this regard, the cartographies obtained for the second wave are especially significant.

The bivariate local spatial autocorrelation analysis between COVID-19 cases in the second wave and the level of gross income of the population is presented in Figure 7. This map shows the concentration of high infection values and low income (HIGH-LOW) in the eastern area of the city, while much of the western area has a low infection concentration and a high income level (LOW-HIGH). The map indicates a social gap in the eastern part of the city, with a significant autocorrelation that demonstrates the inequity in the geographical distribution of the pandemic that more intensely affects the less-favored neighborhoods.

The analysis of the Lorenz curve (Figure S1 in Supporting Information S1) and the Gini coefficients (Table 2) suggest significant imbalances in the distribution of the pandemic, especially in the first waves. This is confirmed because the Lorenz curves have a greater distance from the equity line for the first waves. That is, the distribution of COVID cases was not homogeneous with respect to the resident population in each census tract. Therefore, there was a contrasting level of horizontal inequality; the population that included the lowest social strata was, in turn, those who have suffered and continue to suffer from the most cases of COVID-19.

However, notably, the Gini coefficient values become lower as the pandemic has evolved. Thus, a progressive reduction in its magnitude is shown for the period analyzed. This indicates that the infection has been progressively affecting all social levels and all neighborhoods (Comari, 2015). Some authors consider that the performance of tests by the population could also present geographic imbalances motivated by economic aspects (Schmitt-Grohé et al., 2020). Therefore, the inequity detected in the distribution of the pandemic could be even more severe.

Table 4
Bivariate Spatial Autocorrelation of the Geographical Distribution of COVID-19 Infections by Wave

Moran's local bivariate index	Net income	Average age of the population	Under 18 years	Over 65 years	Average household size	Single-person households	Unemployment rate	Population density
COVID infections Wave 1	−0.017	−0.024	−0.020	−0.020	−0.033	0.021	0.017	−0.04
	p value = 0.313	p value = 0.168	p value = 0.207	p value = 0.224	p value = 0.122	p value = 0.218	p value = 0.291	p value = 0.065
	z score = −0.535	z score = −0.905	z score = −0.748	z score = −0.751	z score = −1.186	z score = 0.788	z score = 0.520	z score = −1.406
COVID infections Wave 2	**−0.291**	**−0.173**	−0.071	**−0.102**	**0.232**	−0.088	0.045	**0.319**
	p value = 0.001	p value = 0.001	p value = 0.007	p value = 0.313	p value = 0.001	p value = 0.001	p value = 0.05	p value = 0.001
	z score = −10.13	z score = −6.147	z score = −2.475	z score = −0.535	z score = 7.928	z score = −3.043	z score = 1.623	z score = 11.06
COVID infections Wave 3	−0.055	−0.070	0.037	**−0.102**	0.006	−0.010	−0.012	**0.124**
	p value = 0.015	p value = 0.002	p value = 0.079	p value = 0.001	p value = 0.403	p value = 0.357	p value = 0.336	p value = 0.001
	z score = −1.998	z score = −2.753	z score = 1.368	z score = −3.653	z score = −2.444	z score = −0.362	z score = −0.415	z score = 4.294
COVID infections Wave 4	−0.034	−0.032	−0.017	−0.054	0.089	**0.112**	0.004	**0.161**
	p value = 0.103	p value = 0.124	p value = 0.272	p value = 0.018	p value = 0.004	p value = 0.001	p value = 0.433	p value = 0.001
	z score = −1.215	z score = −1.146	z score = −0.601	z score = −2.119	z score = 3.244	z score = 3.989	z score = −0.147	z score = 5.80
COVID infections Wave 5	**−0.127**	**−0.126**	**0.151**	−0.096	**0.122**	**−0.175**	−0.009	0.071
	p value = 0.001	p value = 0.001	p value = 0.001	p value = 0.001	p value = 0.001	p value = 0.001	p value = 0.381	p value = 0.01
	z score = −4.511	z score = −4.551	z score = 5.385	z score = −3.522	z score = 4.337	z score = −6.304	z score = −0.368	z score = 2.475
COVID total infections	**−0.111**	**−0.121**	**0.107**	−0.091	0.095	−0.095	−0.001	**0.124**
	p value = 0.001	p value = 0.001	p value = 0.002	p value = 0.002	p value = 0.002	p value = 0.001	p value = 0.482	p value = 0.001
	z score = −3.961	z score = −4.417	z score = 3.843	z score = −3.356	z score = 3.391	z score = −3.434	z score = −0.083	z score = 4.355

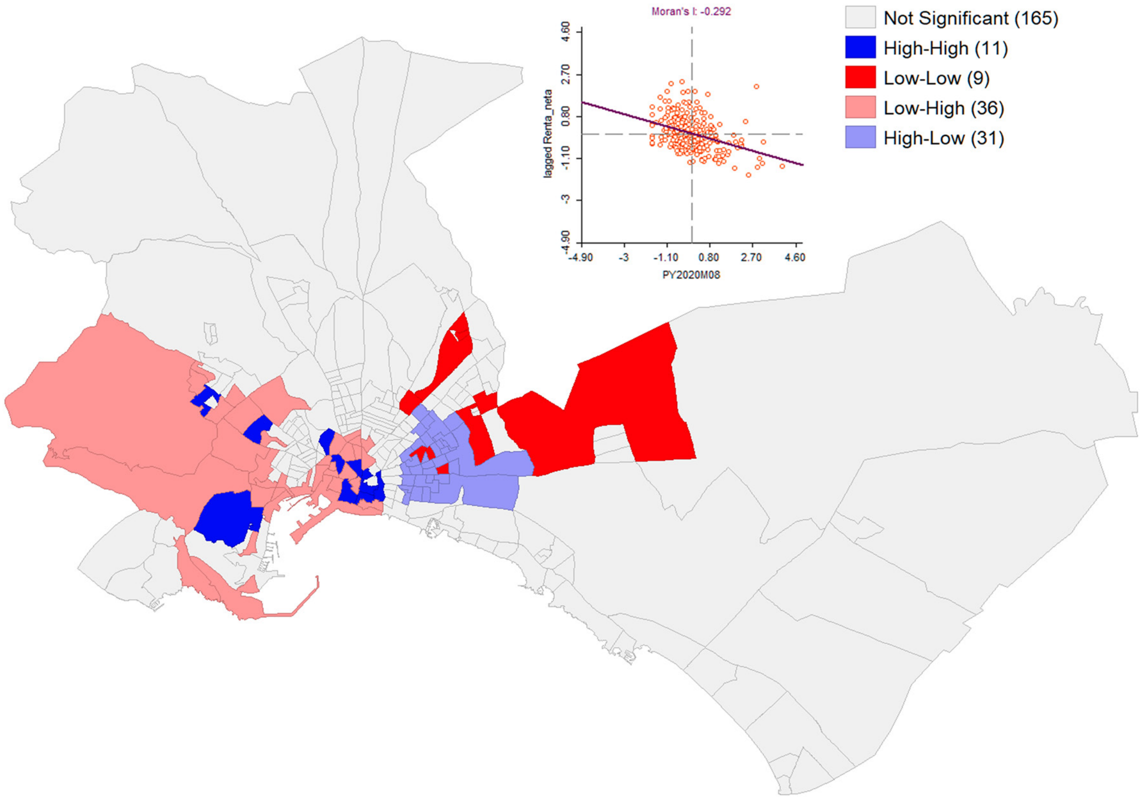

Figure 7. Bivariate local Moran's coefficient between COVID cases and level of net income/inhabitant by census section and LISA clusters.

Several linear regression models have been run using the total COVID infection data and for each of the waves; however, only some significance has been found with the information corresponding to infections in the second wave.

The least square regression (OLS) model performed using infections in the second wave (Tables S1 and S2 in Supporting Information S1) and the socioeconomic variables considered present a relatively low *R*2 value (0.27); however, it confirms the dependence of the number of COVID-19 infections with the following variables: net income (negative sign), household size, percentage of minors (negative sign) and percentage of single-person households. All the variables used are significant at a level of 0.01 and present the expected coefficients. The Variance Inflaction Factor values for the variables (always below the 7.5 threshold) indicate that there are no multicollinearity problems. The other socioeconomic variables considered presented collinearity problems and were eliminated. That is, the number of infections in the second wave is related to low incomes, adults who live in single-person households, and families with a high number of members.

The significance of the Koenker statistic indicates biased standard error products of heteroskedasticity. In this sense, to evaluate the robustness and spatial heterogeneity of the generalized regression model, a spatial autocorrelation analysis of the sample residues was performed (Moran's index: 0.034, *z* score: 2.50, *p*-value: 0.012). A certain degree of clustering was used; therefore, we decided to use the weighted geographical regression (GWR) model.

The GWR model was performed with COVID Wave 2 infections as the dependent variable (August 2020), and the independent variables that showed significance in generalized linear regression obtained an optimal distance band value of 11387.672, an AICc value of 3835.339, an *R*2 value of 0.297., an AdjR2 of 0.273, a Sigma squared value of 231552.423, a Sigma squared MLE of 223939.274 and an effective degree of freedom of 243.714. In addition, Moran's global index of the residuals confirms the randomness in their distribution (Moran's index: 0.018, expected Index: −0.0039, variance: 0.000, *z* score: 1.25, and *p* value: 0.145).

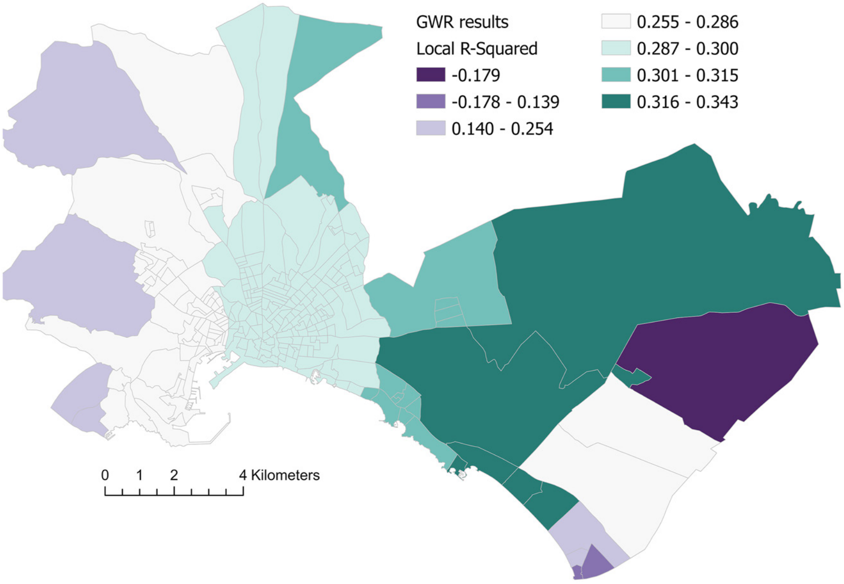

Figure 8. Distribution of the local *R*-squared of the GWR model.

The AICc value of the GWR model is lower than that of the generalized linear regression, which is why it is more appropriate. Figure 8 shows the geographical distribution of the *R*2 values obtained with the GWR model, which clearly shows that the eastern sector of the city is better represented by the model.

The results must be interpreted with caution because the *R*2 values obtained in general do not explain more than 30% of the variance. In any case, there is evidence of a health gap in the city that reproduces the economic-social gap that exists at the base.

In the neighborhoods of the eastern periphery of the city where poverty and vulnerability are concentrated, the risk of infection increases because it is not difficult to reduce social contact. The causes can be diverse, first because many people do not have their own vehicle and use public transport on a daily basis (Pérez-Arnal et al., 2021), which favors contact between people and increased infections. Additionally, social isolation has caused an effect contrary to what was expected. The overcrowding of the low-income population in homes that are a few square meters has caused many psychological (Abel & McQueen, 2020) and health (diabetes, hypertension and obesity) (Alkon et al., 2020) problems and also increased the risk of infection.

The social contrast between tourist neighborhoods and working-class neighborhoods makes Palma a strongly unbalanced city in the economic and social sphere that results in a general lack of spatial justice. No specific geographic pattern of the pandemic has been found in relation to tourism activity. The most touristy neighborhoods have not shown a specific grouping pattern or a greater concentration of cases.

The neighborhoods with the greatest economic deprivation are also those with the lowest level of services and green areas and are less liveable, which has made the fight against the pandemic more difficult.

Public policies to mitigate the pandemic have not had the sensitivity or financial and political capacity to address the health emergency or to prevent and stop the territorial configuration of vulnerability in urban spaces (Luna Nemecio, 2021). Therefore, it is evident that the health crisis has served to highlight the great inequality of Palma and the effects of globalization.

Transition strategies toward sustainable and resilient cities in the context of the current global ecosystem and climate crisis have been called into question by the effects of the pandemic. This situation has led to a question of urban development models and urban planning from new perspectives (Gesto, 2020).

The pandemic should be interpreted as an opportunity to reestablish necessary spatial justice in cities (Gil & Undurraga, 2020). In fact, it provides an opportunity to reexamine urban planning and rebuild a more resilient urban environment. Therefore, sustainability should promote scenarios of equity, inclusion, and social and environmental justice (Haase, 2020).

In this sense, Alraouf (2021) proposes the need for more sustainable planning, making cities more compact, reducing forced mobility, and responding to the architectural-housing challenges of improving residences to make them more liveable and spaces where people can work, exercise, learn, play, and relax (Gesto, 2020).

In particular, in addition to the social inequality in the distribution of the pandemic, the economic effects of COVID-19 in Palma have been devastating because COVID-19 directly affects tourism activity. From sun and beach tourism to cultural tourism, all tourism sectors have been affected. Some authors have indicated an opportunity to develop new proposals for more sustainable tourism (Gómez, 2021). The pandemic has caused a massive loss in tourism employment in a generalized way (Sun et al., 2022) that is more pronounced in the low-level social sectors, further widening the social and economic gaps in the city.

In this line of urban regeneration, several authors propose relevant issues that should necessarily be considered for Palma:

1. Develop a territorially sensitive approach to managing health crises as a learning direction to redirect social inequality that guarantees spatial justice (Capanema-Alvares et al., 2021). In tourist environments, this territorial sensitivity in crisis management actions must be rigorous and exhaustive, acting on specific depressed geographical areas. In this sense, it is recommended that the geographical scales of crisis management strengthen the local sphere over more generic regional approaches.
2. Reorient the territorial model to be more age-friendly to improve the quality of life of elderly people and mitigate the effects of pandemics (Buffel et al., 2020), and prioritize investments in depressed areas and in local development at the neighborhood level to integrate older people in the design of policies. In particular, in the case of Palma, it is important to recognize that the city welcomes retirees from all over Europe and that urban and health planning of the city guarantees a healthy and safe environment.
3. Managing a different territorial matrix, as pointed out by Cenecorta (2020), implies designing other policies, consensuses, and processes of governance and social participation for the transformation of cities in favor of productive, orderly, and sustainable development. Palma requires the development of integrated urban, environmental, social, health, and tourism planning policies that allow the construction of sustainable urban scenarios. Urban policies must be redesigned to strengthen the preparedness of cities for risks and their capacity to respond and become more resilient, intelligent, sustainable, and inclusive (Gesto, 2020). To improve the city's resilience to future epidemics, it would be advisable to increase green spaces in the city to encourage people to be physically active (Garrido-Cumbrera et al., 2022).
4. Develop community-based health prevention interventions as a solution to prevent the effects of pandemics (Buffel et al., 2020). Public participation in the development of policies should be considered a priority, especially in the framework of the integration of tourist activity in the city.
5. Tourist congestion or overtourism in the city of Palma requires planning instruments

The results obtained use census tracts as geographical reference units. In this sense, some authors note that the use of large geographical units can lead to significant errors, so the use of georeferenced point data is recommended (Garcia-Morata et al., 2022). However, the problem in these cases is to ensure the anonymity of the data.

A relevant question that has not been raised in the paper and will be the subject of further study is the influence of vaccination on the spatio-temporal distribution of infections (Mollalo et al., 2021). The income level and socio-economic characteristics of the neighborhoods could have a fundamental influence on this aspect (Basak et al., 2022). To date, it has not been possible to obtain geolocalized information on the vaccination campaigns carried out in Palma, but we hope to be able to cover this issue in the future.

This research has opened up the possibility of carrying out new studies on the influence that COVID-19 has had on different socioeconomic variables such as income levels, unemployment, housing quality, commercial activity and tourism in the city of Palma, some of which we are currently developing.

4. Conclusions

The temporal distribution of COVID-19 infections in Palma for the March 2020–March 2022 period shows five waves that correspond to the months of April 2020, August 2020, December 2020, July 2021, and January 2022. An increase is shown, that is, progression of cases from the first wave to the fifth wave. The number of deaths from COVID-19 shows a pattern similar to the number of infections, but with a delay of 1 month. In addition, broader wave peaks can be observed that last more than a month. The waves coincide with the high tourist season and the holiday period at the end of the year, a fact that proves an increase in infections driven by interpersonal contact. There does not seem to be a specific pattern that justifies a greater number of cases with tourist activity.

The spatial distribution of COVID-19 cases throughout the study period shows specific clustering patterns for each of the waves. The first wave strongly affected census tracts in the northern part of the city where nursing homes and hospitals are located. The second wave showed a higher level of territorial concentration of cases (Moran index = 0.16). There is a concentration of infections in the neighborhoods of the eastern part of the city (Son Gotleu, Estadi Balear, Pere Garau, etc.). The third wave repeats the expansion patterns of the second wave but expands slightly toward the north (sa Indioteria). In the fourth wave, there was a generalized expansion of infections in the city, without a specific pattern. Finally, the fifth wave maintains the patterns of the second and third waves, but in a less significant way. At the territorial level, a grouping model justified by tourism development in the city is not identified. In fact, tourist areas in no case specifically show an increase or concentration of cases.

The analysis of the geographical distribution of the socioeconomic variables of the city of Palma reveals patterns of poverty concentration in the eastern expansion of the urban area. In these areas, there is a low income level, high number of family members, lower level of aging, high level of unemployment, and other dynamics of impoverishment and deprivation. The Moran index for income distribution is 0.58, indicating a high concentration of poverty.

The bivariate autocorrelation analysis (Moran's bivariate) shows a clear relationship between the concentration of COVID-19 infections and low income, especially in the second wave (Moran's bivariate: −0.291 between net income and the number of COVID-19 infections). The relationship between the average age of the population and the average size of the household is also significant. The distribution of cases in the fifth wave and the total number of infections also confirm these relationships.

The equity analysis performed in relation to the distribution of COVID-19 infections for each of the waves indicated high Gini coefficients, suggesting a significant inequality framework and a notable level of geographical concentration of infections. Likewise, the evolution of the pandemic shows a model of generalized expansion, so that the greater number of infections manifests itself in greater geographic expansion.

Regression models confirm the dependence of the number of COVID-19 infections on the level of socioeconomic deprivation of the neighborhoods. In this way, households with low income and a high number of family members are those with the highest probability of infection. Finally, and notably, the GWR model shows better predictive capacity in the eastern part of the city.

The results reveal that Palma is a city with strong socio-economic contrasts that have manifested themselves in the distribution of the COVID-19 pandemic. It is necessary to implement multidimensional territorial planning models that integrate environmental, social, economic, tourist, etc., aspects to build a more resilient and sustainable city. It is necessary for the geographical scales of the intervention to be more precise and to develop local policies for the prevention and management of the pandemic that guarantee spatial justice for its inhabitants. The tourism sector in the city urges the city to develop rapid mechanisms for mitigating the effects of health emergencies to prevent not only the loss of competitiveness as a tourist destination, but also to guarantee its own economic subsistence.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

There are restrictions on the availability of data for the set of information on COVID-19 cases provided by the Platform of Research in Health Information of the Balearic Islands (PRISIB), due to the signed agreements around data sharing. Requestors wishing to access data set of information on COVID-19 cases provided by the PRISIB used in this study can make a request to the PRISIB Steering Committee chair: idisba.prisib@ssib.es. The request will then be passed to members of the PRISIB Steering Committee for deliberation.

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