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Infrastructural inequality: exploring the emergence of digital classes in the Metropolitan Area of Santiago, Chile

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Abstract. This paper examines the digital divide in the city of Santiago, Chile. The research uses the density of mobile phone antennas as a proxy for digital infrastructure. The findings show that there is a strong correlation between the density of mobile phone antennas and socio-economic status. Areas with higher incomes and more mobile phone antennas have better Internet connectivity than areas with lower incomes and fewer mobile phone antennas. The objective is to shed light on the power dynamics and invisible networks that shape the configuration of infrastructures, highlighting the need for equitable access to the digital world as a fundamental democratic right. The conclusions indicate that communication infrastructures are unevenly distributed and that the transition from analogue to smart cities risks exacerbating social inequalities. Rectifying these disparities is essential to avoid leaving the most vulnerable behind in technological transitions.

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1. Introduction

The vitality of urban space is not solely composed of good buildings and streets but also of the network systems that allow the flow of information between spaces. This research aims to understand how telecommunications infrastructure, represented herein by mobile phone antennas, reproduces the same patterns of segregation and socio-spatial inequality that characterise the city of Santiago (Agostini, 2016), generating new spaces of digital exclusion and the emergence of new digital classes. These digital classes constitute enclaves composed of exclusion zones where the lack of Internet connectivity creates significant barriers to access to information, services and relational dynamics.

In Chile, the COVID-19 health crisis has driven a rapid shift towards the digital world in various social activities, to the extent that information technologies have become an essential asset in households' daily lives (Deloitte, 2021). Digital infrastructure is one of the fundamental components for maintaining resilience and economic recovery (Valdés, 2021). In the case of the Santiago metropolitan conurbation in Chile, the territorially limited availability of broadband Internet services and the lack of access to public institutions concentrate inequality in urban peripheries, where the population is mostly vulnerable and segregated (Sabatini et al., 2001; Rodríguez & Winchester, 2001; Agostini et al., 2016; Valenzuela-Levi, 2022).

These infrastructural impediments are associated with socio-spatial contexts, hindering certain city territories from carrying out virtual activities satisfactorily and without interruption (Zaballos et al., 2020). In this research, we understand infrastructure as the set of elements or services necessary for the proper functioning of a territory or institution. Specifically, digital infrastructure refers to a telecommunications network that provides the necessary elements for operating and managing digital environments. It encompasses digital equipment revolving around the development of hardware systems, software, material installations, and digital components for information and communication technology services to the population (Valdés, 2021). This article studies digital infrastructure as the density of mobile phone antennas in the metropolitan region of Santiago, since the use of smartphones has managed to penetrate most of the Chilean population more than any other digital device. In this sense, antennas constitute critical infrastructure for Internet access for different groups of population.

Given the segregating logics of the telecommunications market (Valenzuela-Levi, 2020), the digital divide emerges as an essential problem, creating new inequalities in terms of the creation of different groups of digital subjects in the city, which differ based on their access to digital infrastructure. These differentiations can be compounded by other contextual factors such as housing characteristics, educational level or situation, and employment status, among others (Gonzales, 2015). Legislation is not originally designed to prevent the generation of these gaps, and recent urgencies have been magnified by the pandemic. For this reason, under the cost–benefit logic of public policy design in Chile, telecommunications companies sometimes deliberately exclude certain areas from their networks and connection infrastructures. This practice, known as "red-lining" (Norton, 2013), stems from the stigmatisation of territories and their populations based on sociodemographic, racial and economic attributes, thereby excluding potential users.

Studies on digital gaps and inequalities help to clarify the factors that contribute to certain population groups being systematically digitally segregated, as well as the dimensions and consequences of this reality. Among the elements that sustain the gap are levels of digital literacy, which go hand in hand with inequalities in access to digital tools. In recent years, issues surrounding digital divides have reportedly diminished due to the widespread use of smartphones as digital tools propelled by public policy. However, this has sparked a significant debate about the population's consequences, as the World Development Report by the World Bank (2016) indicates that this phenomenon, despite promoting Internet market expansion, has not successfully reduced the existing digital divide. Access to the Internet and digital capabilities and skills vary depending on the device and the quality of the service (Kaasinen, 2009; Hyde-Clarke & Van Tonder, 2011).& Van Tonder, 2011; Kaasinen, 2009).

According to Valenzuela-Levi (2020), this phenomenon is not simply a result of a demand problem in specific territories but is the institutionally produced logic of digital exclusion. Thus, what is observed in metropolitan areas such as Santiago and other cities in the Global South is not just the presence of urban ghettos but also the growing expansion of digital ghettos and the creation of a digital underclass. Link and Phelan (2001) argue that, in many cases, the stigma attached to these segregated or excluded groups described earlier leads to difficulties in accessing opportunities, precarious incomes, and poor quality of life, among other issues.

Therefore, when delineating the conceptual boundaries that allow for a discussion of the digital experience, it is the context of the "red zone" and the prevailing market logic in the country that reinforces this digital divide. This perpetuates the existence of subordinate individuals in the face of a well-connected urban society, as they experience spatial segregation and material discrimination, along with stigmatisation by private and public institutions. Sennett (1994) categorises these individuals as undesirable groups, who also face high levels of poverty and unmet needs. This distribution logic of digital services can be defined as the digital divide, which we understand as "the difference between those who have access to the web and those who do not" (Ragnedda & Muschert, 2013: 10). This creates a binary perception of having or not having access to the Internet. There is also a problem of usage capabilities. The digital divide is not solely about material access to digital infrastructure and devices but also about having the technical skills required to use new technologies (Katz & Gonzales, 2016).

Therefore, those with lower digital capabilities become a digital underclass. Due to the socio-economic inequality affecting certain territories, methods have emerged for digitally subordinate individuals to access the virtual space using limited means. For example, there is an increasing Internet access among lower-income sectors through mobile phones or smartphones, a phenomenon that characterises the economically disadvantaged populations in developing countries (Napoli & Obar, 2014). As the presence and ownership of Internet-enabled mobile phones expanded, studies examined the impact on those accessing the Internet for the first time through these more affordable devices. Mobile access opens new possibilities for those without fixed means of access, providing opportunities for growth in social, political and economic spheres (Castells et al., 2008; Chigona et al., 2009).

Chile's digital landscape is open to scrutiny. According to Correa et al. (2018), Chile possesses three notable characteristics regarding Internet coverage: it ranks among the countries with the highest levels of connectivity in Latin America (ECLAC, 2016); it exhibits a high degree of smartphone usage; and it has a historical public agenda that encourages the use of mobile devices. Smartphone penetration is such that, as of December 2022, according to data provided by the Ministry of Telecommunications in its databases, Chile had 22 million operational mobile devices for a population of 19 million. In 2017, 97.2% of Internet users in Chile accessed the Internet through fixed or mobile broadband connections, with smartphones becoming the most popular device for Internet access, utilised by 71.4% of the population. Laptops followed at 46.8% and desktop computers at 39.9%. In just seven years, Internet access through smartphones skyrocketed from 13.4% in 2010 to an impressive 95.1% in 2017 (SUBTEL, 2017).

The advent of mobile Internet access has increased penetration rates in areas with historically marginalised social groups (Tsetsi & Rains, 2017). The literature suggests that new inequities are emerging concerning the potential use and skills required to take advantage of the Internet (van Deursen & van Dijk, 2014). Acknowledging that not all Chilean citizens have access to the necessary infrastructure for continuous Internet connection, the study raises concerns about territorial differentiations with socio-economic biases in urban areas that affect people's accessibility to digital services. This manifestation of inequality, known as "digital segregation", describes the inequities in access and use of new information and communication technologies (Chaparro, 2007). In Latin America, these disparities appear in multiple dimensions as a result of a stratified society influenced by social dynamics of marginalisation. Localised digital gaps in specific sectors are the product of structural constraints such as Internet red-lining (Cesare et al., 2017).

The magnitude of this situation is exemplified by Bustos (2021) through the Social Broadband Barometer, which provides data on the extent of digital disconnection in the context of the pandemic in Santiago, Chile. In Santiago's municipalities, such as Las Condes or Vitacura, connectivity levels even surpass those of developed countries. In contrast, nearly half the population in peripheral areas, particularly in municipalities like La Pintana, lacks access to the Internet. Consequently, the survey on Internet access and usage conducted by the Ministry of Telecommunications (2017) illustrates how certain territories are excluded from specific types of digital services. For instance, the municipality of La Pintana, with the lowest income households in the city, has only 13.5% of households with fixed Internet access, highlighting the significance of Internet connection through mobile devices.

Consequently, we can frame the study of digital divides in relation to disparities in population's access and quality of service when it comes to utilising technological tools. To achieve this, we will employ the concept of sub-connection, which goes beyond the binary approach of the digital divide that merely focuses on whether or not access exists. Instead, it seeks to comprehend the complete spectrum of connectivity possibilities (Katz, 2017). This entails understanding the various forms of digital inequality that are closely linked to the socio-economic and infrastructural reality of residents in marginalised and vulnerable areas, who find themselves in an economically disadvantaged situation (Katz, 2017). The material resources available to Internet users limit their degree of access and utilisation. According to Hargittai (2008), a more comprehensive perspective on digital inequality recognises how a person's socio-economic status can influence their access to and usage of the Internet. This is supported by various studies that conclude that mere access does not provide advantages to users of information and communication technologies (ICT) (Lawson-Mack, 2001; Hargittai, 2008).

Understanding digital divides and inequalities as manifestations of socio-economic disparities leads us to question the situation of certain historically disadvantaged groups, such as the elderly population in the country. Kaztman (2005) highlights that most of the elderly population is socio-economically marginalised and emphasises the urgent need to improve digital infrastructure in urban areas to enhance the quality of life for older people. These improvements aim to facilitate access to a greater amount of information about various services and essential goods for this population, including medical clinics, pharmacies, green areas and socialisation opportunities. This panorama reveals how technology reinforces social stratification and creates new disparities in digital divides, which, in turn, exacerbate the longstanding issues faced by segregated and marginalised territories within the city (Norris, 2001).

Given these circumstances, questions arise regarding the capacities of countries' digital and energy infrastructure to sustain the progression of social dynamics towards the world of information and communication technologies. With this objective in mind, we analyse the situation in the Santiago Metropolitan Area, taking into account the distribution and density of cellular telephone antennas in relation to the distribution of households based on their level of socio-economic vulnerability. The aim is to examine how the spatial distribution of cellular antenna infrastructure reproduces patterns of territorial inequality and segregation, increasing levels of social exclusion, particularly among lower-income households, and leading to the formation of new digital classes.

2. Research materials and methods

The present investigation is based on a deductive and exploratory quantitative approach, aiming to analyse the existing socio-spatial relationship between communication infrastructure, represented by the distribution of mobile phone antennas, and socio-spatial inequality, represented by the distribution of households based on their levels of socio-educational vulnerability, along with the diversity of land uses throughout the city.

The study area analysed corresponds to the Metropolitan Area of Santiago (AMS), capital of Chile, a city of 78,035.9 hectares that is home to 6,071,531 inhabitants, according to data from the latest housing and population census (INE, 2017), who are grouped into 34 municipal districts (Fig. 1).

It is a mainly extensive city, but with strong inequalities in the distribution of its housing density, with highly populated areas in the city centre, as well as in the highly populated peripheries, due to the neoliberal housing policies developed during 1980 and 2000 that expelled the most vulnerable population to the periphery in large social housing complexes, lacking in architectural and urbanistic quality (Ducci, 1997; Hidalgo, 2007).

These processes linked to housing policy and the deregulation of land markets have given rise to a large city (more than 30% of the national population lives here) with strong nuances due to high degrees of territorial inequality and residential segregation (Sabatini et al., 2001).

Firstly, to estimate the levels of spatial inequality in communication infrastructure, the database of registered mobile phone antennas provided by the Undersecretariat of Telecommunications (2022) for the Santiago Metropolitan Area was utilised. This database, which corresponds to July 2022, includes information on the location of each antenna, the company to which it belongs, and the type of signal it provides (ranging from 2G to 5G), as illustrated in Figure 2.

For practical analysis purposes, the density of antennas was estimated based on their location using the Kernel Density tool in ArcGIS 10.8 GIS software. This tool determined the total number of antennas per km^2 (square kilometre) by utilising a default influence area derived from the spatial distribution of the antennas themselves, corresponding a diameter area of 964 metres, the resulting antenna density data per km2 was subsequently assigned to each census tract of the 2017 *Census* (INE, 2017).

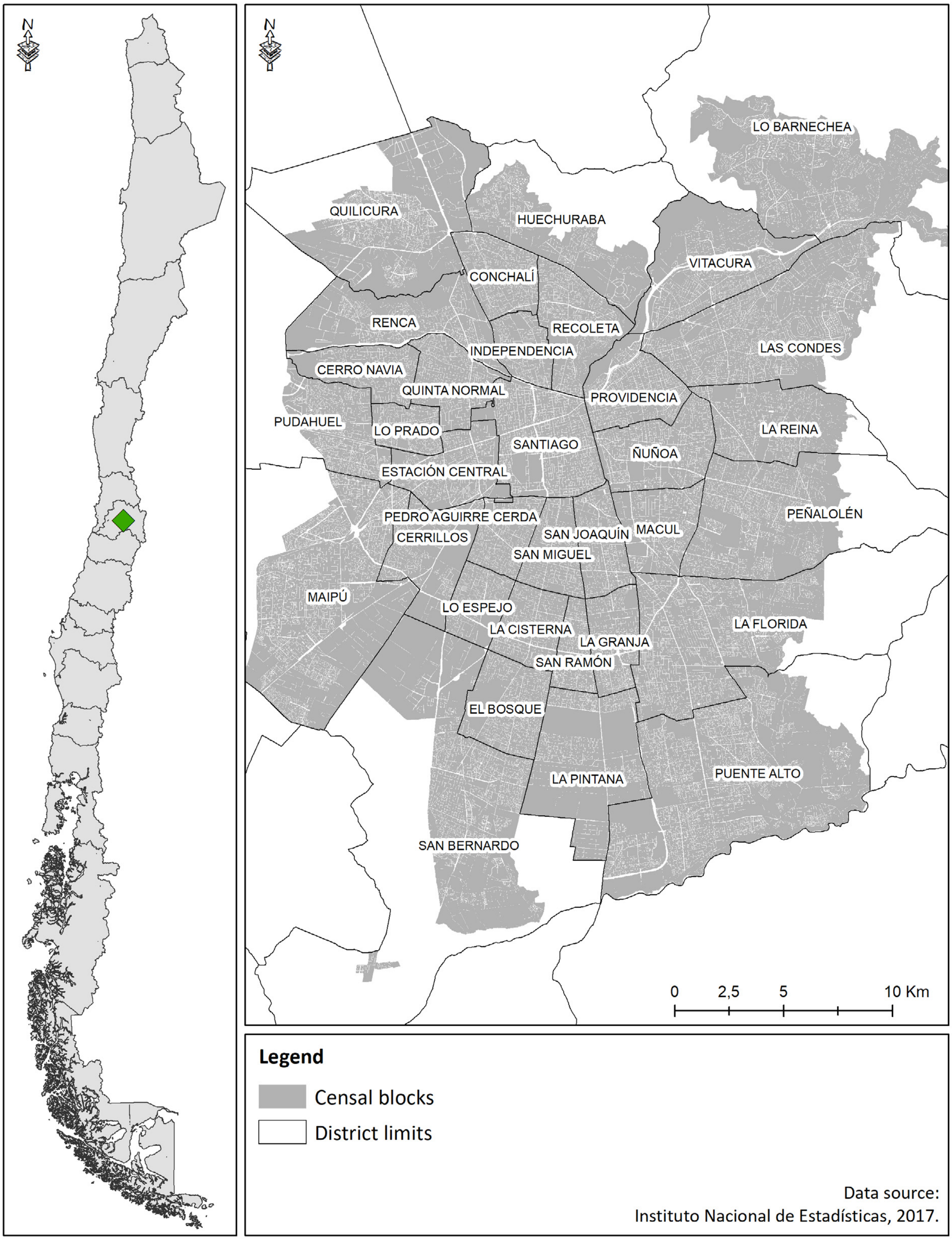

Fig. 1. Study area, Metropolitan Area of Santiago, Chile

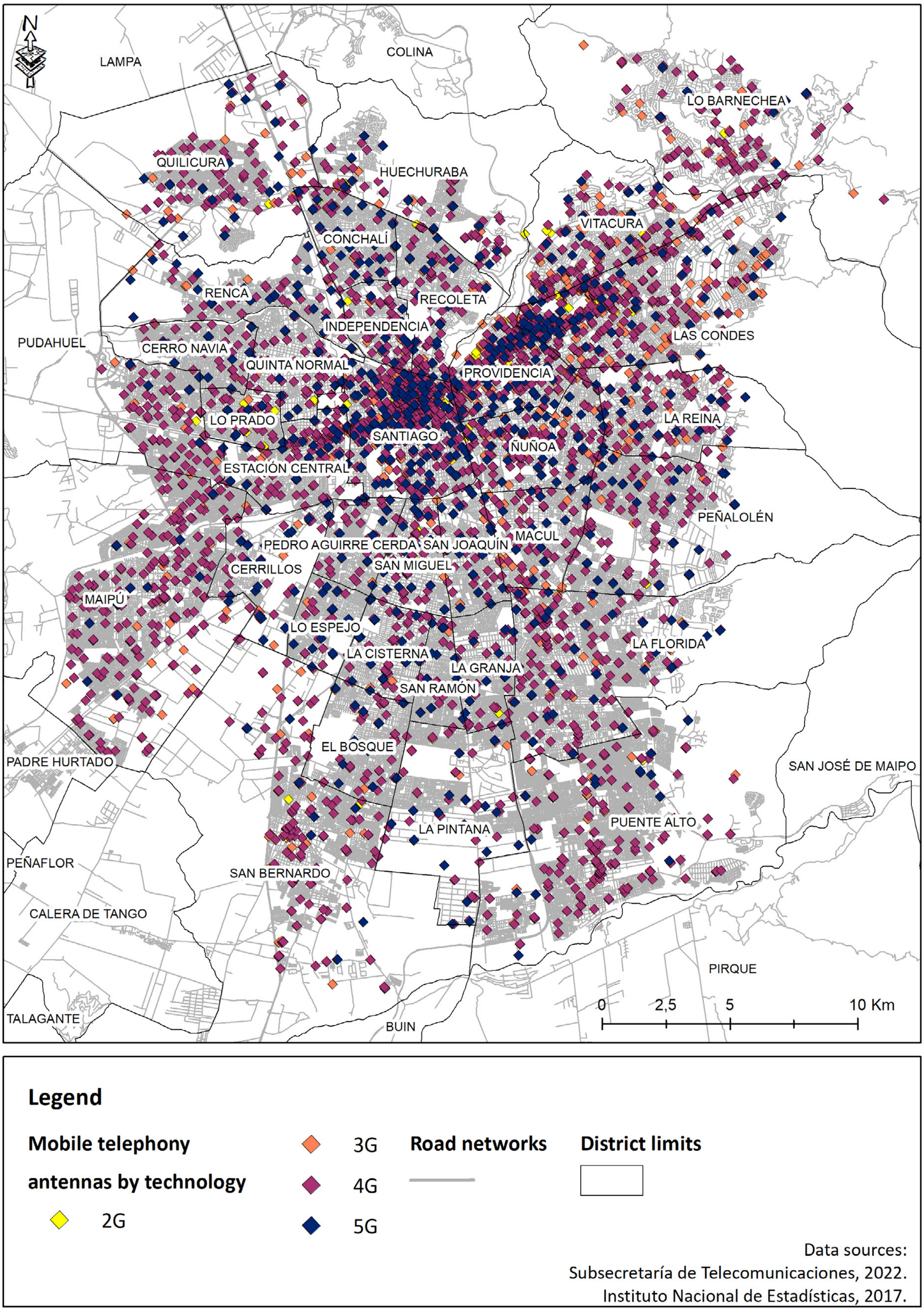

Fig. 2. Mobile telephony infrastructure in the Metropolitan Area of Santiago, Chile

Secondly, to estimate the distribution of households according to their level of socio-educational vulnerability, the average years of schooling for the population aged 24 and above at the census tract level were employed. This information was obtained from the microdata of the 2017 *Housing and Population Census* (INE, 2017). It is worth noting that years of formal education serve as an excellent proxy for household vulnerability and income levels, as various studies have indicated (Encinas et al., 2022).

Thirdly, considering that mobile telephony services not only cater to household communication but also to the population that moves daily, we employed (as a proxy variable) land use diversity, based on the hypothesis that higher land use diversity leads to greater influx of transient population (Cheng, 2017) and increased access to goods and services, as proposed by Truffello and Hidalgo (2015) and Fuentes et al. (2022).

To determine the aforementioned land use density, we relied on data from the Construction and Appraisal Registry of the Internal Revenue Service (SII, 2018). This registry provides detailed information on the total number of buildings and m^2 for each of the 20 destination types recorded by the SII. Using this data, we applied the Shannon diversity index (Shannon, 1948) to estimate the diversity of constructed m2 per destination in relation to the diversity of buildings in the region.

$$H = \sum_{i=1}^{S} pi * \ln pi$$

Where:
H: Shannon diversity index,
S: number of existing destinations,
pi: proportion of m^2 of destination i, with respect to the total built m^2 (i.e., the relative abundance).
abundance).

An exploratory analysis was conducted on the three variables under study: mobile antenna density, average years of schooling and land use diversity. The spatial distribution of these variables was analysed using the spatial statistics software GeoDa (Anselin et al., 2006). This analysis aimed to determine the level of spatial autocorrelation, measured through Moran's Index, which helps ascertain whether the spatial distribution pattern is dispersed, random or clustered across the territory. Additionally, it sought to identify statistically significant clusters of high and low values in the study area (Anselin, 1995).

Moreover, a second stage of exploratory analysis is proposed, employing cluster analysis through the K-means methodology. This approach aims to divide the study area into K groups that exhibit maximum similarity based on the three selected variables (Anselin et al., 2006). This step will enable the identification of socio-spatial patterns that shed light on the relationship between these inequalities and the mobile telephony infrastructure.

3. Research results

The first outcome of the analysis is presented in Figure 3, displaying the average density of antennas per km^2 by census zones. The figure reveals a highly concentrated pattern around the central and eastern areas of the city, along with specific subcentres in the communes of Maipú, La Florida and Puente Alto. These cases align with the polycentric structure of the city described by Truffello and Hidalgo (2015), where this extensive sector of the central-eastern zone and the respective subcentres predominantly correspond to areas with significant commercial and labour activities. This is closely associated with the high diversity of activities and land uses present in these sectors (Fuentes et al., 2022).

On the other hand, the low density of telecommunication infrastructure in the peripheral sectors of the city translates into limited possibilities for digital connectivity, especially in residential areas of the communes of Quilicura, Lo Barnechea, Puente Alto and La Pintana. This phenomenon of digital disconnection illustrates the territorial economic inequalities manifested as infrastructural disparities, constituting forms of marginalisation and digital exclusion.

Regarding the distribution of the adult population based on their level of education, using census data (INE, 2017), a segregated pattern is evident that has characterised the city of Santiago for decades. This is in line with studies by Sabatini et al. (2001) and Agostini et al. (2016). There is a pronounced concentration of the population with higher educational and financial capital in the eastern zone of the city, contrasting with the lower-income households predominantly found in the north-western to south-eastern peripheries (Fig. 4).

Similarly, analysing the diversity of uses for built destinations based on records from the Internal Revenue Service (2018) yielded a pattern closely resembling the distribution of mobile phone antenna density. This already provides evidence of the relationship between this type of infrastructure and

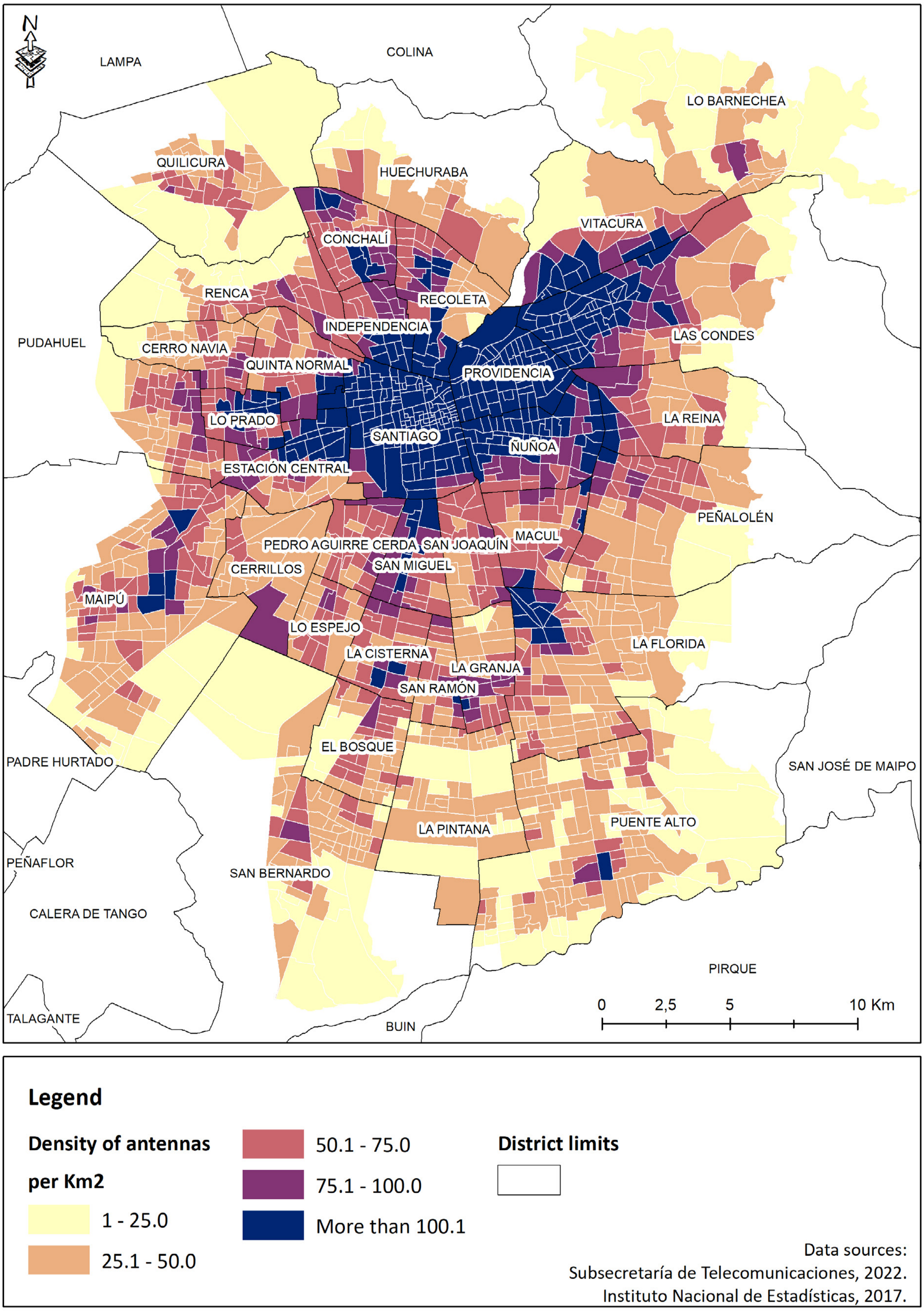

Fig. 3. Antenna density distribution in the Metropolitan Area of Santiago, Chile

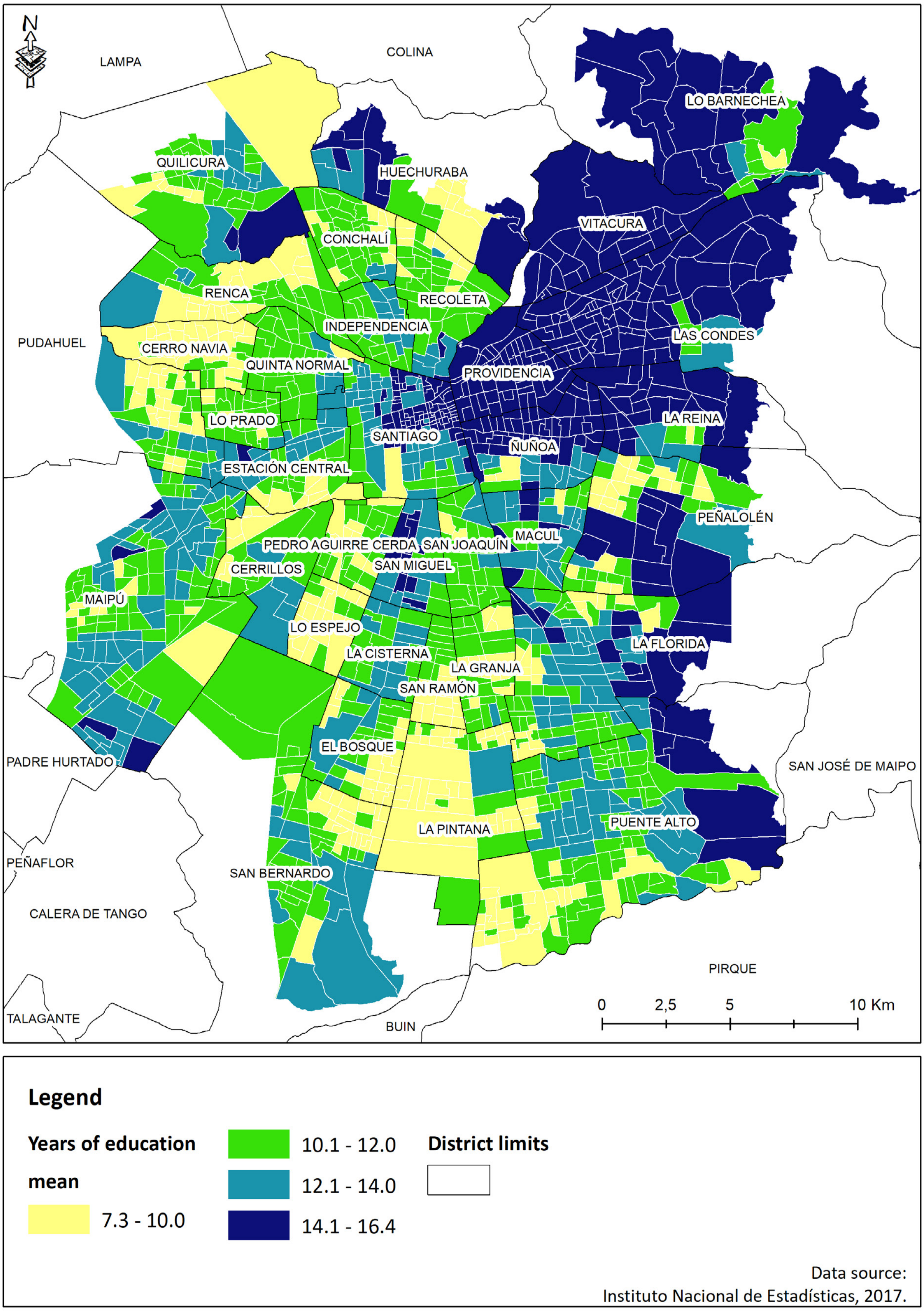

Fig. 4. Population distribution by years of education in the Metropolitan Area of Santiago, Chile

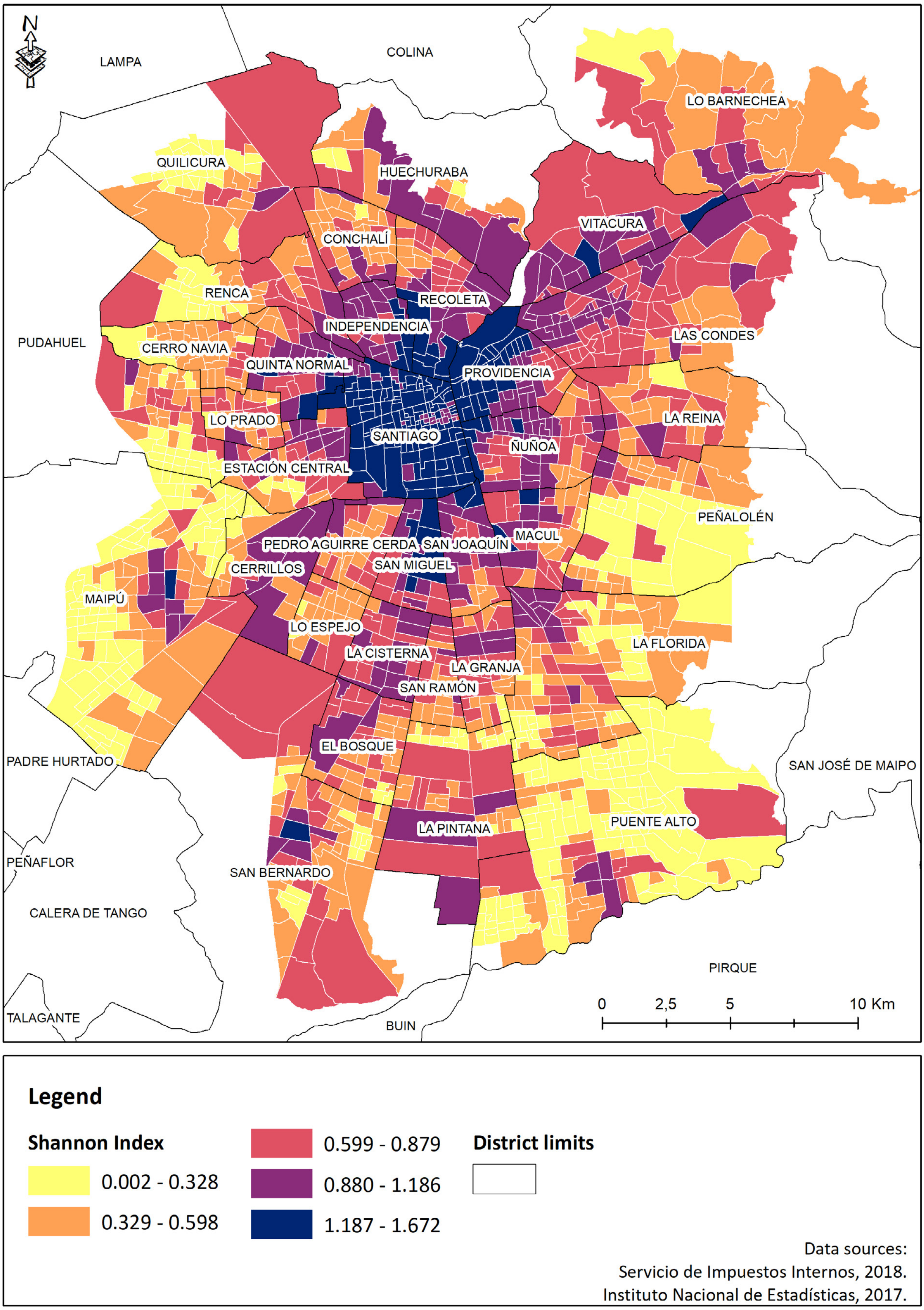

Fig. 5. Land use diversity in the Metropolitan Area of Santiago, Chile

the spatial organisation of the city (Fig. 5). The city exhibits a polycentric structure, with a significant concentration in the central and eastern sectors, where a wide range of activities and employment opportunities are concentrated (Truffello & Hidalgo, 2015).

The clear similarity in distribution patterns among educational levels of the population, land use diversity and the location of telephone infrastructure provides initial evidence for considering the possibility of a concentrated and significant distribution pattern. This pattern would reinforce the levels of residential segregation that have always characterised this city. Consequently, telecommunications infrastructure could be a potential factor in the reproduction of such spatial inequity, as it severely limits connectivity and communication possibilities for lower-income households.

This is partly confirmed when analysing the levels of spatial autocorrelation using Moran's Index (Anselin, 1996) for the three variables under examination. The density of antennas shows a spatial autocorrelation level of 0.895, while the autocorrelation for average years of schooling reaches 0.805. As for land use diversity, the autocorrelation index reaches 0.502, indicating a clear concentrated pattern for all three variables across the territory.

This is further supported by mapping the configuration of these clusters onto the territory through spatial autocorrelation analysis. The significant concentration areas with both high (red) and low (blue) values for both variables can be observed in Figure 6.

When examining the location of high-value clusters, it is evident that they tend to overlap in the central and eastern areas of the city, with the most prominent cluster corresponding to years of schooling. In contrast, the low-value clusters (blue) are distributed less evenly in the peripheral sectors of the city but still follow a pattern that aligns with the three most vulnerable sectors: Renca, Cerro Navia, Lo Prado; Cerrillos, Pedro Aguirre Cerda, Lo Espejo; and parts of El Bosque, San Ramón, La Granja and La Pintana.

This spatial configuration, which confirms the urban dynamics between the central-eastern zone and the rest of the periphery, is not entirely consistent, particularly when considering the spatial distribution of low-value antenna density clusters. Only in the eastern zone of the city do we observe a concentration of low values. Based on these observations, a cluster analysis using K-means was

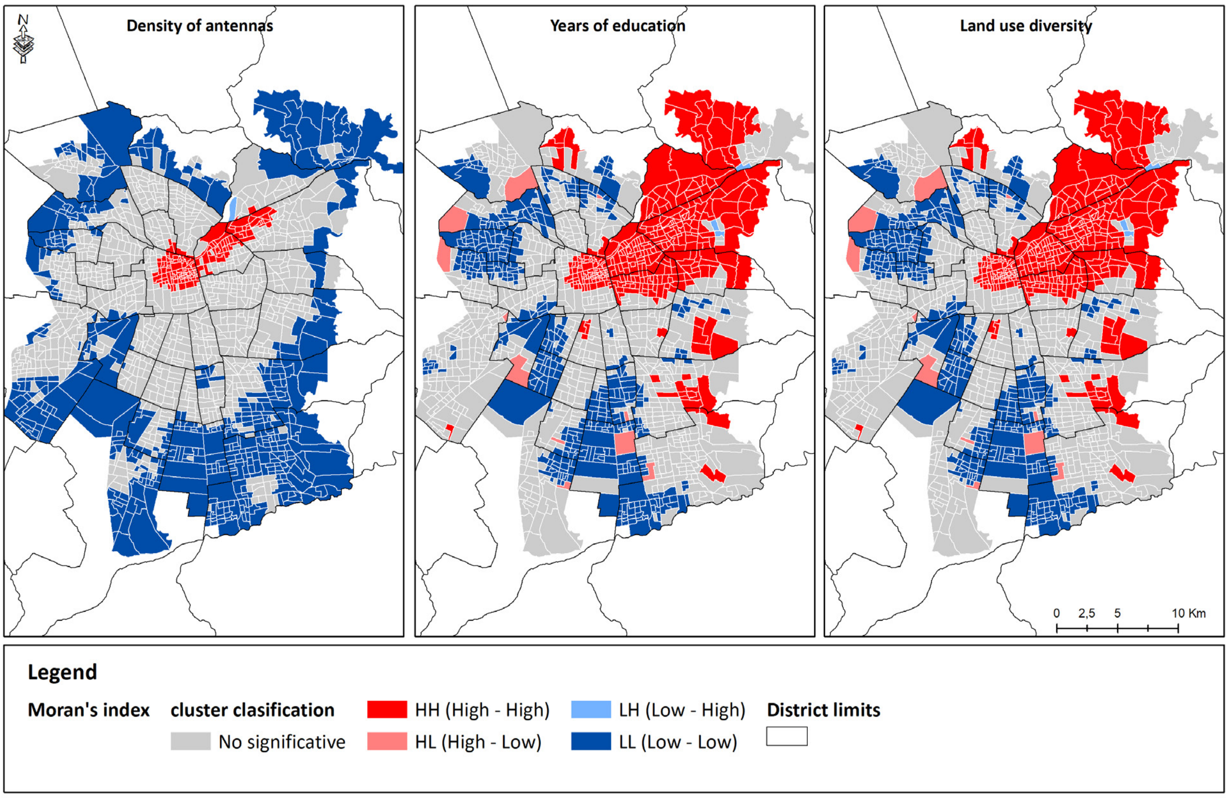

Fig. 6. Clusters of mobile antennas, years of education and land use diversity

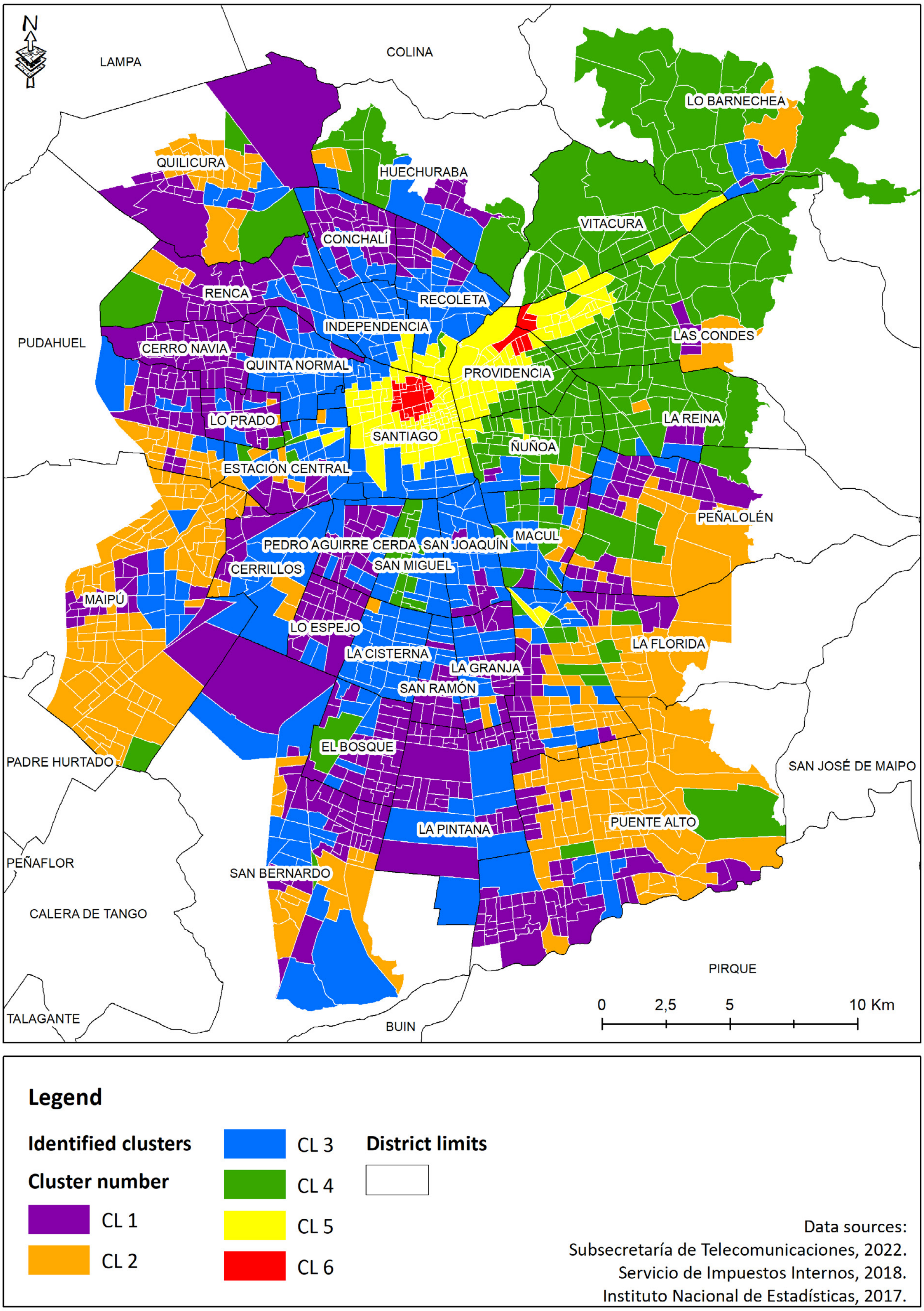

Fig. 7. Spatial distribution of cluster results by K-means

applied to identify six typologies of spatial clusters, as shown in Figure 7.

From the summary in Table 1, we can determine that the first cluster, corresponding to number 1 (in purple), represents the most disadvantaged zone in terms of connectivity and socio-spatial inequality. This sector has the lowest antenna density per km2 (49.9), the lowest average years of schooling (9.9), and very limited land use diversity (0.439). This zone encompasses 31.97% of the total households in the AMS, which mostly consist of highly socially vulnerable households.

The second cluster, indicated by the orange colour, is quite similar to cluster 1. It exhibits lower antenna densities and land use diversity but higher average years of schooling (12.4). It includes a mix of low-, middle- and even upper-middle-income households. This sector accounts for ~21% of the analysed households in the region.

On the other hand, cluster 3 (in blue) represents more central areas of the city, characterised by higher antenna density (73.3) and greater land use diversity (0.928), but similar levels of schooling compared to cluster 2. However, this area is also one of the most densely populated, comprising 19% of the households in the study area.

Additionally, cluster 4, depicted in green, extends across a significant portion of the eastern sector of the city. It has a higher average year of schooling (15.1), greater antenna density per km2 (91.7) and a Shannon index similar to that of cluster 3 (0.800). This cluster represents the Santiago elite, as it not only enjoys greater access to formal education but also has double the antenna density and greater land use diversity compared to clusters 1 and 2. This indicates a higher level of physical and digital connectivity to various city services. These circumstances reinforce the accumulation of income, assets and services that other households in the city, especially those from vulnerable areas, strive to access (Correa, 2015).

Finally, clusters 5 and 6 represent the most vital sectors of the city, characterised by the highest antenna density, reaching as high as 920 per km^2 in cluster 6, along with high land use diversity (1.265 and 1.354 respectively). However, these clusters account for only 12.2% of the households, since they primarily consist of non-residential destinations but encompass most of the city's goods and services.

It is essential to highlight the stark contrast between clusters 1 and 4, as they represent the most vulnerable and highest-income sectors of the city, respectively. This highlights the strong socio-territorial inequalities in Santiago, which have been analysed by various authors (Rasse et al., 2021; Hidalgo & Bordoff, 2005; Sabatini et al., 2004). In this case, the disparities are reinforced by lower levels of schooling, limited access to city services and a low density of mobile infrastructure, which is crucial for facilitating connectivity among residents in these neighbourhoods.

This highlights the precariousness faced by the population residing in environments with unstable connectivity, which complicates their ability to meet the demands of a hyperconnected world. Consequently, they experience limited access to services, information and the new social spaces for interaction and dynamism. These challenges pose significant problems for this digital underclass, which will only grow if the dynamics of digital development remain unchanged.

This situation represents a serious issue of inequality and exclusion. In addition to the substantial material and economic deficiencies experienced by households in these areas, originating from housing policies in the 1980s (Ducci, 1996;

Table 1. Summary of clusters

Number of cluster	Mean value by cluster			
	Antennas by km^2	Years of education	Land use Shannon index	Percentage of households
1	49.9	9.9	0.439	31.97%
2	41.3	12.4	0.256	20.94%
3	73.3	11.4	0.928	19.00%
4	91.7	15.1	0.800	15.89%
5	289.9	14.7	1.265	10.48%
6	920.2	14.9	1.354	1.72%

Source: Prepared by the authors

Hidalgo, 2007), there is also the creation of a barrier to communication. Katz (2017) argues that although mobile-only connectivity is already a form of sub-connection, as the full potential of the Internet is better harnessed through more capable devices like computers, relying solely on mobile connections that are unstable further exacerbates the sub-connection status due to device and infrastructure gaps. According to the author, the large number of families who can only access the Internet via mobile devices are at a disadvantage due to the limitations in their capabilities.

In this context, where incomplete or unreliable access instruments and infrastructures exist, and users are aware that their connection can be interrupted at any moment, this is the digital reality faced by sub-connected individuals in marginalised territories. Even with some form of connection, it does not guarantee the satisfactory fulfilment of all digital requirements for activities to thrive (Rice & Katz, 2003).

4. Conclusions

Keller Easterling (2014) argues that the invisible networks behind infrastructures are not only conduits for information and energy, but also powerful forces shaping the configuration of such infrastructures. With the digitalisation of society and the seemingly inevitable implementation of smart cities as a cornerstone of governance, ensuring access to the digital world becomes essential as a democratic right. Otherwise, the advancement of smart cities will tend to shape the collective urban space based on the needs of fragmented groups within the population rather than the entirety (Calzada, 2021).

The findings of this article indicate that communication infrastructures are unequally distributed. In this scenario, the technological shift from the analogue city to the smart city will reproduce pre-existing inequalities. This inequality needs to be addressed.

One of the enduring lessons and effects of the pandemic has been the increased use of smartphones for social interaction. This has created new territories shaped by algorithmic modelling of individual or collective interests and digital proximity placebos. In these pandemic territories, a connection was forged between telecommunication and everyday life.

In this emerging everyday life, the presence of people living with unstable or absent connectivity complicates accessing a hyperconnected world that relies on digital infrastructures. The limitation of this access is already considered a violation of human rights, and it is urgent for states to catch up and ensure equitable affordability (United Nations, 2011). This disparity in access is already visible on the shared maps, where areas with higher incomes and higher antenna density house only 16% of the population, while areas with lower incomes and lower antenna density house 24.8% of the population.

As Ben Campkin suggests, infrastructure brings visibility to spaces of interconnection, assigning social and economic value to elements that are often overlooked in the city but are crucial to its functioning (2020). Mapping the apparent patterns of inequality in cellular network connectivity helps us understand that these infrastructures also mirror conditions present in income distribution, access to healthcare, quality housing, educational levels and countless other disparities evident in Greater Santiago. Rectifying this problem is a pending task in the configuration of the collective space, before the relentless advance of big data leaves the most vulnerable behind, as often happens in capitalist technological transitions (Zuboff, 2018).

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