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The process of metropolisation and Spatial Accessibility. The case study of the Cagliari Metropolitan City

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Abstract. With the complex processes of metropolisation, increasingly broad and reticular, which connect and mix different settlement forms (central areas, suburbs, medium-sized cities, peri-urban areas…) the spatial reorganization of land-use and urban functions also manifests itself: residence, work, services, study, trade and leisure.
Furthermore, the consequences on the distribution of urban functions and on the transport system are also substantial, radically transforming the lifestyle of the communities, especially for the more numerous ones in peripheral areas. Accessibility is a key issue for scientific disciplines applied to territorial governance. In fact, it expresses the level of organization of the territory and in particular of the services, for this reason it is considered as a fundamental aspect for its proper functioning.
Furthermore, with the transition from the municipal administrative dimension to the metropolitan one, accessibility assumes a preponderant role for the governance of the metropolitan cities/region increasingly characterized by multi-directional and multi-purpose mobility and by a significant vulnerability of the community. In this framework, the aim of the paper is to develop a methodological approach to support metropolitan city planning (policy target) through the combination of spatial autocorrelation of the different accessibility intensities (private and public) and social-material vulnerability index (SMVI).

Keywords: Circular City, Urban Accessibility, Spatial autocorrelation, LISA, Metropolitan City Planning.

1 Introduction

Private and collective vehicular accessibility is a key issue for urban government, characterized by a progressive densification of the population. Urban areas, in fact, host more than half of the world's population with a forecast of around 70% in 2050. It is also estimated that every day, globally, cities make around 7.5 billion movements between goods and people. This is a trend destined to increase, so much so that in 2050 there could be an increase in the movement of people three to four times higher.

In recent decades, mobility flows have become a key component of urbanization, shaping the urban form [1], with direct effects on the environment and the community. However, despite the increase in urban mobility globally, access to the services, places and activities that cities offer is increasingly difficult. In this sense, the 15-minute city model aims to respond to complex urban dynamics [2].

In fact, the urban form and distribution of functions is strongly influenced by infrastructure and private transport flows responsible for urban dispersion. Furthermore, urban contexts are increasingly places of community vulnerability, resulting from exposure to risk factors that can compromise the relative well-being of people, following exposure to crises and risks (economic, social and environmental). The improvement of accessibility and the reduction of the vulnerability of communities constitute the main field of investigation of this manuscript. The aim of the manuscript is to develop a methodological approach to support metropolitan planning (policy target) based on the spatial autocorrelation of the different accessibility intensities and the social and material vulnerability index (SMVI). The paper is organized as it follows: paragraph 2 Literature review; paragraph 3 Materials and Method; 3.1 Study Area; 3.2 Data; 3.3 Methodology; 3.4 LISA Method; paragraph 4: Results and Discussion and paragraph 5 Conclusion and future development.

2 Literature review

Resilient and sustainable urban development, in line with the 2030 goals, is increasingly its importance. In this sense, accessibility, in addition to being closely connected with urban physical development, influences urban logistics and citizens' welfare [3]. It is therefore necessary to shift the focus from mobility to urban accessibility. In fact, if it is true that the speed and efficiency of the journey are important, a more important role must be covered by the ease with which destinations are reached, it follows that mobility is not the aim to be pursued, but means to achieve the goal of widespread accessibility [4]. In this sense, some researches highlight how urban accessibility requires transport planning based on the combination: mobility, land-use and digital accessibility [5, 6]. According to the main field research [7, 5] use of telecommunications affects travel. In particular, digital connectivity reflects the availability of digital infrastructure and one or more devices (modes). Digital accessibility reflects being able to use digital connectivity to engage in activities. Digital connectivity is necessary but not sufficient to provide digital accessibility, which is closely related to the quality of available and affordable digital services and the skills and preferences of the community. With the

post covid-19 the car remains the preferred mode of transport by Italians. From the 19th Report on mobility "Audimob - Mobility styles and behaviors of Italians" [8], it emerges that in 2022 the growth of private mobility is reconfirmed. The private modal share almost reaches the 65% threshold, one and a half points higher than the pre-Covid level. In 2021, the car fleet continued to grow but not to rejuvenate: its average age increased to 12.2 years compared to 11.8 in 2020. The total number of cars on the road is just under 40 million with a motorization rate that has risen to 67.2 vehicles per 100 inhabitants (66.6 in 2020). The motorisation rate in Italy therefore remains among the highest in Europe with a circulating fleet of over 11 million vehicles that do not exceed the Euro 3 emission standard (just under 30% of the total).

As regards, on the other hand, pedestrian mobility, after the years of the health emergency, in 2021 it drops to 22.7% of the total, over 6 points less than in 2020, and in 2022 (first half year) it drops further to 19.7 %. In 2022, for LPT there is a reduction in passengers of -21% compared to 2019 and a demand volume of -12% is expected a the end in 2023 compared to the pre-Covid scenario [9]. Furthermore, if on the one hand private accessibility and LPT fulfills the right to mobility, on the other it contributes to the progressive growth of the phenomenon - nationally and internationally - of urban metropolisation. This phenomenon can be described as an urban cluster, where the functions that consume a lot of space (leisure, commerce, industries) are in the periphery, while the city centers are reserved for privileged housing and high-value activities (Central Business District). As such, metropolisation produces spatial and social ruptures within the relevant urban space, but also between the urban space and the peripheral region of metropolitan influence. Metropolisation and relative accessibility are therefore the focus of this manuscript.

3 Materials and Method

3.1 Study Area

The study area is the Cagliari metropolitan city which is the major city of Sardinia Region. The city of Cagliari is the capital of the Sardinia Region and Metropolitan City since 2016, and is the most important cultural, economic, political and administrative center of Sardinia. It is an administrative structure of 17 municipalities. The Municipality of Cagliari hosts over 150 000 inhabitants, while the Metropolitan City spans nearly 420 000 inhabitants [10]. The metropolitan city of Cagliari was chosen to test the methodology. This choice is justified by the collaboration with Mlab srl, which operates mainly in the metropolitan context of Cagliari.

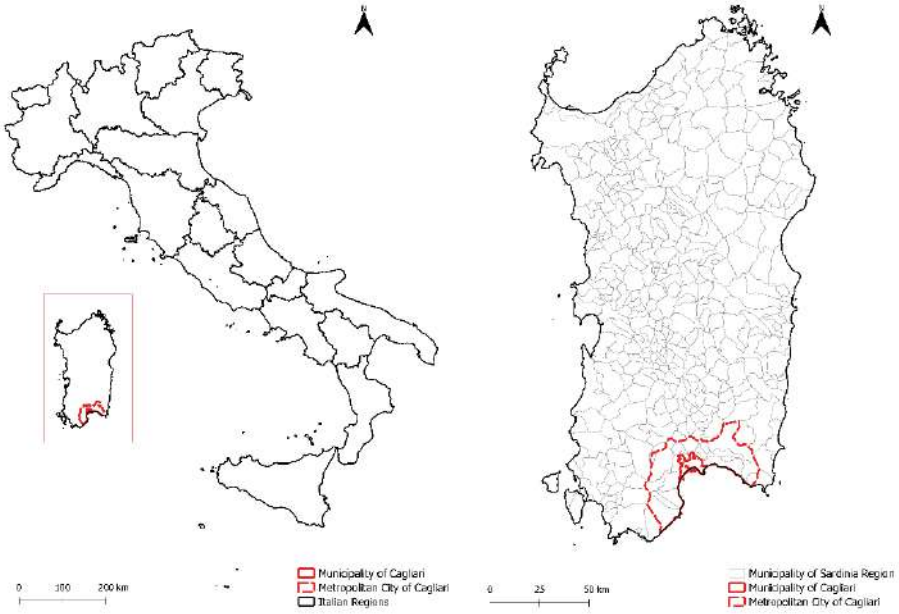


Fig. 1. Cagliari metropolitan city (Sardinia, Italy) (Author: M. Sinatra, 2023)

3.2 Data

Spatial accessibility, social and material vulnerability of communities and population size constitute the main data set used in this manuscript. In particular, thanks to the concession of Mlab srl, accessibility maps of the metropolitan city of Cagliari (private and LPT) are available, which has developed a traffic model to support various mobility studies and plans (Urban Mobility Plan, Minimum Services Plan, Feasibility studies of the new tramway network). The accessibility map is based on approximately 780 traffic zones, and has made it possible to calculate the itineraries between all the origin-destination pairs and the relative travel times. The social and material vulnerability index (SMVI) elaborated by ISTAT is a composite indicator of seven sub-indicators and expresses the different aspects of a multidimensional phenomenon of vulnerability with a single value. Population data were extrapolated from the Urban Atlas Copernicus database (2018, edition) [11].

3.3 Methodology

The proposed method consists in the observation of the phenomenon of accessibility in the metropolitan city dimension. The representation of the phenomenon is based on spatial autocorrelation by virtue of the nature of the observed phenomenon. **Table 1** highlights the proposed methodology, framework and main references.

Table 1. Urban accessibility interaction of territorial dimension and methodology framework (Author: G. Balletto, 2023).

Step	Phenomenon	Spatial Dimension	Literature
1	Urban Accessibility	Multi scale/Metropolitan City Spatial autocorrelation LISA	[12, 13, 14, 15]
2	Vulnerability	Municipality	[16]
3	Policy Target	Municipality/Metropolitan City	[17, 18]

Specifically, the accessibility autocorrelation represents the relationship between the ease of access to a certain resource or service in one area and the ease of access to that same resource or service in another nearby area. The analysis of the accessibility autocorrelation can therefore be useful to identify areas where accessibility is poor or inadequate, to investigate the causes. Furthermore, it can be used to evaluate the effectiveness of policies and interventions aimed at improving accessibility. In general, the autocorrelation of accessibility is an important indicator for evaluating the equity and sustainability of cities, in particular allowing to evaluate whether services are equally distributed in relation to accessibility (public and/or private).

3.4 LISA Method

Spatial autocorrelation indicators are tools that allow to observe the behavior of a variable with respect to its position in space and in particular with respect to what happens in its proximity. Through two categories of information, such as location and related properties, it is therefore possible to describe geographical objects. The first law of geography, formulated by Waldo Tobler (1970) [19, 20, 21], states that "All events are related to each other, but nearby events are more related than distant ones". The main characteristic of local indicators of spatial autocorrelation (LISA) is the measure of the degree of spatial association relative to each territorial unit and its neighboring elements. In particular, the Local Moran Index makes it possible to evaluate for each position the similarity of each observation with nearby geographical objects. This can be seen as the sum of all local indices and is proportional to the value of the Moran:

$$\sum_i I_i = \gamma * I \tag{1}$$

The index is calculated as follows:

$$I_i = \frac{(X_i - \underline{X})}{s_x^2} \sum_{j=1}^{N} (w_{ij}(X_j - \underline{X})) \tag{2}$$

where:

- N is the number of geographical units;
- X_i is the variable describing the phenomenon under investigation in region i;
- $\underline{X}$ represents the sample average and $(X_i - \underline{X})$ it is the variable's average deviation;

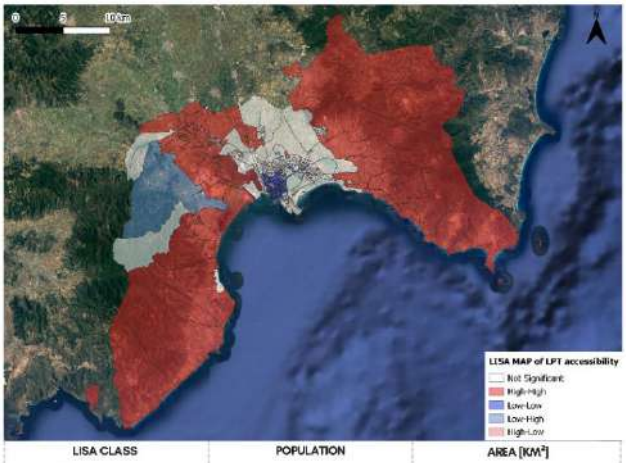
- S_x^2 is the Standard deviation;
- w_{ij} is the weight matrix.

From its application it is possible to obtain five combinations:

- High-High: there are high values of the phenomenon and high levels of similarity with the nearby areas (hot spots);
- Low-Low: there are both low values of the phenomenon and low levels of similarity with the nearby areas (cold spots);
- High-Low: high values of the phenomenon and low levels of similarity with the nearby areas are detected (potential outliers);
- Low-High: low values of the phenomenon and high levels of similarity with nearby areas are highlighted (potential outliers);
- No significant autocorrelation values are detected.

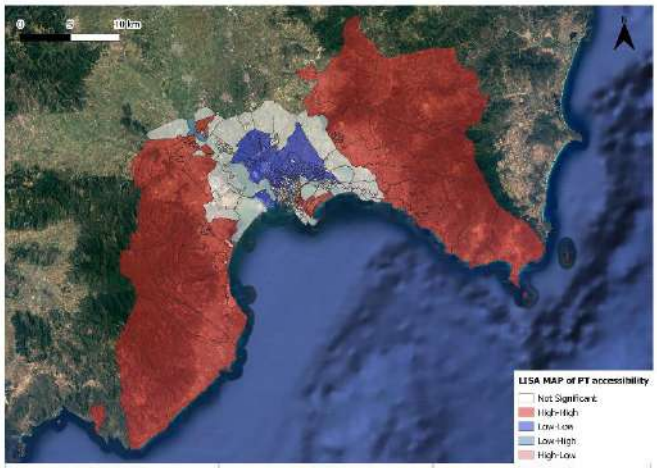
4 Results and Discussion

The analysis was conducted considering the Local Public Mobility (LPM) and Private Transport (PT) accessibility (2022) attributed by census section or aggregation of the metropolitan city of Cagliari, Sardinia, Italy. Those data were used as input for the calculation of the LISA and in particular of the local Moran's Index. The analysis has been performed on 2021-22 data from Mlab srl. The Moran Index aims to group areas in terms of similarity in a selected attribute, together with a spatial contiguity. The analysis carried out highlights a clustering configuration of high-high autocorrelation (red area) municipalities in the outer belt of the metropolitan city of Cagliari and low-low autocorrelation (blue area) in the old center of Cagliari city for LPT (**Fig. 2**). The analysis carried out highlights a clustering configuration of high-high autocorrelation (red area) municipalities in the outer belt of the metropolitan city of Cagliari and low-low autocorrelation (blue area) in the suburbs (North-West) of Cagliari city for PT (**Fig. 3**).



LISA CLASS	POPULATION	AREA [KM²]
Not Significant	248 135	268.9
High-High	96 935	1232.2
Low-Low	83 685	11.4
Low-High	1 795	111.5
High-Low	887	0.2

Fig. 2. LISA map of LPT accessibility and population estimated data for each Urban Atlas polygon, 2018 [11] (Authors: M. Sinatra and G. Balletto, 2022)



LISA CLASS	POPULATION	AREA [KM²]
Not Significant	217 229	251.4
High-High	89 675	1279.5
Low-Low	123 487	88.7
Low-High	560	4.4
High-Low	518	0.4

Fig. 3. LISA map of PT accessibility and population estimated data for each Urban Atlas polygon, 2018 [11] (Authors: M. Sinatra and G. Balletto, 2022)

In particular, the non-significant area (LPT and PT) is an object of interest because it represents spatial contexts where accessibility is discontinuous. From **Fig. 2** and **Fig. 3** it can be seen: non significant area (nsa) relating to: LPT= 268.9 km^2 with non-existent population pop. nsa LPT 248,135 and PT=251.4 km^2 with non-existent population pop. nsa PT= 217,229. Furthermore, the non-significant area (LPT and PT), although presenting an intermediate extension compared to the other LISA classes, is characterized by a high insistent population, over half of the population of the metropolitan city. For this reason, a further index was considered, provided by ISTAT, the so-called Social and Material Vulnerability Index [22].

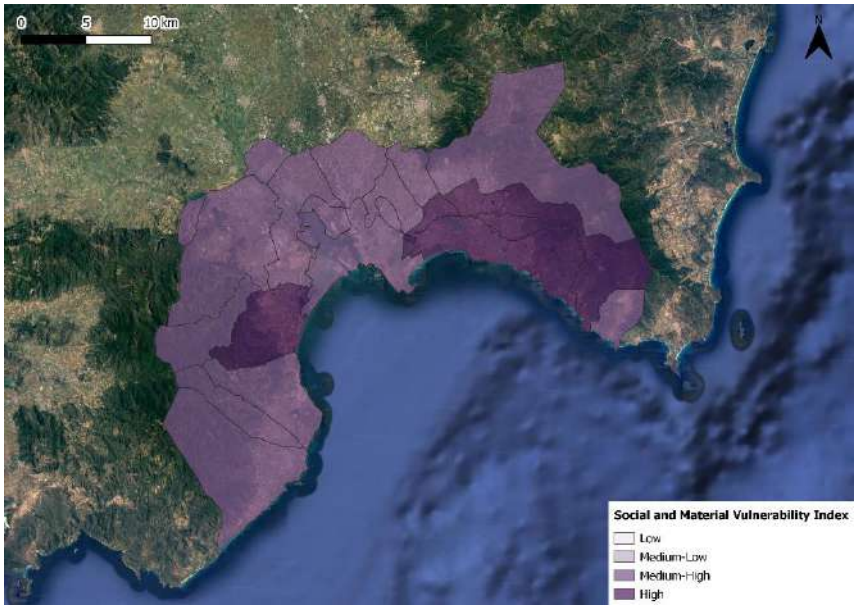


Fig. 4. Social and Material Vulnerability Index map [23] (Author: M. Sinatra)

This Social and Material Vulnerability Index (municipal level) describes the synthetic measure of the level of social and material vulnerability of the communities and is obtained from the combination of seven different sub-indicators such as: percentage incidence of the population aged between 25 and 64 illiterate and literate without qualification of study; percentage incidence of families with 6 and more members; percentage incidence of young single-parent families (age of the parent less than 35 years) or adults (age of the parent between 35 and 64 years) on the total families; percentage incidence of families with potential welfare hardship, to indicate the share of families made up only of elderly people (65 years of age and over) with at least one member over eighty; percentage incidence of the population in conditions of severe crowding, given by the percentage ratio between the population residing in dwellings with a surface area of less than 40 m^2 and more than 4 occupants or in 40-59 m^2 and more than 5 occupants or in 60-79 m^2 and more of 6 occupants, and the total population residing in occupied dwellings; percentage incidence of young people (15-29 years) outside the

labor market and school training; percentage incidence of families with potential economic hardship. Furthermore, from the overlap between the spatial autocorrelation of the accessibility of the private and public system and the vulnerability index (**Fig. 4**) it is possible to obtain **Table 2** summarizing the results, in which the relative policies target have been associated. In particular: improve local public transport (LPT) in the Municipalities of Capoterra and Maracalagonis; improve both the transport and LPT infrastructures (I) for the Municipalities of Quartu Sant'Elena and Quartucciu.

Table 2. Summary results and Policy Target (Local Public Transport - LPT and/or Infrastructure - I).

Municipality	Autocorrelation of accessibility	Municipal percentage area	Vulnerability Index (Istat)	Policy Target: improve
Capoterra	High-High	100 %	Medium-High	LPT
Maracalagonis	High-High	100 %	High	I & LPT
Quartu Sant'Elena	High-High	100 %	High	LPT
Quartucciu	High-High	60 %	High	LPT
	Not Significant	40 %	Medium-High	I

5 Conclusion and future development

Transport accessibility in urban areas is becoming particularly challenging for transport planners and managers, a process accentuated by a set of concurrent causes occurring in the latest few years.

During the most recent years transport systems, and particularly public transport, was challenged by the Covid-19 experience and the post-Covid period that put a threat to the already difficult quest for a modal shift in transport towards the public mode. The distancing policies and a generalized unease of gathering into transport means during the Covid-19 pandemics, and a rediscovered, if not never abandoned, preference for the private transport mode, are delaying to pursuing a recovery of public transport to the pre-Covid - and hopefully higher – shares. This is also coupled with other import processes ongoing, as urban sprawl, population ageing and, generally, changes occurring in the spatial balance of wealth distribution. All of these elements are producing considerable effects on urban areas, including a difficulty of serving a population sprawling over wide areas. The analysis of national statistical data in fact shows that the Metropolitan City of Cagliari is increasing in its size in terms of population in the years, but with considerable changes intervening inside, involving a deconcentration of the core – as the Municipality of Cagliari – and an increase of the population of the municipalities of the ring, as those surrounding the city of Cagliari or even farther. This, led also by the changes in urban rents and therefore a less affordable housing market in the center, is coupled with a need to serve a sparse population with a frequency and quality of service that cannot be the same as that of a central, dense area. As a consequence,

these areas become more and more difficult to serve and can become less and less willing to rely on public transport for their daily trips. In a sense, the trend – quite generalized, and not limited to the case of Cagliari – of urban and metropolitan areas in particular, is that of settling towards a three-tiers system, more than to a center-periphery one, with a core, a mixed-density ring, and a peripheral ring. The second, mixed-density ring is characterized by a certain level of 'sparsely dense' population together with a difficult to achieve adequate public services supply, what, in transport terms, makes it more difficult to serve such areas.

The results obtained so far with the analysis carried out and presented in this paper are consistent with such a situation, portraying areas of dependence from private transport, those where a stronger resistance of public transport can be observed, and intermediate areas more deprived in terms of such services. These latter ones deserve a more thorough attention and analysis in order to understand the metropolitan, as well as the local scale and obtain important information on potential policies to put in action.

Authors contribution. Conceptualization, methodology, formal analysis, materials and resources, software and validation: all authors. Data curation: Balletto, Sinatra and Sechi. In particular: Balletto wrote Sections 1 and 2; Sechi and Fancello wrote Sections 3.1 and 3.2; Sinatra and Balletto wrote Sections 3.3 and 4; Sinatra wrote Section 3.4; Borruso wrote section 5.

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