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Article

Evaluation of Urban Accessibility Through Geomarketing Techniques: Case Study in Valencia (Spain)

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Abstract: Today's world is becoming increasingly urbanised, with populations concentrated in cities. This trend underscores the need to monitor urban growth and its potential adverse effects. The 2030 Agenda for Sustainable Development, the European Urban Agenda, various local agendas, and the "15-Minute City" concept aim to mitigate these effects, particularly climate change-related ones. This paper explored the role of accessibility to public transport, services, and green urban areas (GUAs) in achieving the goals of SDG 11: Sustainable cities and communities and examined the feasibility of establishing 15-min cities by evaluating urban indicators. The methodology applied geomarketing techniques within geographic information systems (GISs) using high spatial resolution and influence buffers rather than conventional buffers for a more accurate assessment. These results offer a comprehensive and specific view of the city's situation, based on the case study of Valencia (Spain), and provide urban planning tools for decision-makers with accessibility evaluated as a percentage at the block level.

Keywords: accessibility; 15-Minute City; urban indicators; Sustainable Development Goals (SDGs); geomarketing

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1. Introduction

Sustainable development is a broad term that describes policies, projects, and investments that provide benefits today without sacrificing future environmental, social, and personal health [1]. These policies are focused on limiting human development's environmental impact [2] as they fight one of the main challenges of the modern world: adapting cities to the climate emergency [3].

The United Nations (UN) has made this term the main topic for defining goals and measures to be taken worldwide. In 2015, the Sustainable Development Goals (SDGs) were established as a universal call to action to end poverty, protect the planet, and improve the lives and prospects of everyone everywhere. The UN Member States adopted the 17 Goals as part of the 2030 Agenda for Sustainable Development, outlining a 15-year plan for their achievement [4]. While significant progress has been made [5], the Decade of Action (2020–2030) needs to deliver the Goals by 2030 [6].

Sustainable development is crucial in urban contexts, as 56% of the global population currently resides in cities [7], a figure expected to increase to 68% by 2050 [8]. Urbanisation is intrinsically linked to the three dimensions of sustainable development: economic, social, and environmental. Urban sustainability is defined as the city's multidimensional capacity to operate successfully in those dimensions simultaneously [9]. Understanding the interconnections between these dimensions is essential for guiding cities toward sustainable development pathways.

This rapid urban growth highlights the critical importance of SDG 11, "Sustainable cities and communities". This goal is also known as the "Urban Goal", which calls for cities and human settlements to be made inclusive, safe, resilient, and sustainable, emphasizing the need for proactive planning and sustainable policies [10].

Various urban agendas have been developed to bring SDG 11 to the local level [11]. The New Urban Agenda (NUA) was adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III) in Quito in 2016. It was the first internationally agreed document detailing the implementation of the urban dimension of the SDGs [12], as more than 80% of citizens will be living in urban areas by 2050 [13]. Following this, the European Commission created the Urban Agenda for the EU, which was adopted in the Pact of Amsterdam in 2016 [14]. Spain followed suit by launching its Spanish Urban Agenda in 2019 inside the "Plan de Acción para la Implementación de la Agenda 2030 en España" [15]. These initiatives provide frameworks for cities to become more sustainable, inclusive, and resilient, aligning with the principles of accessibility and sustainability outlined in SDG 11.

In parallel with these agendas, the Paris Agreement was adopted at the UN Climate Change Conference (COP 21) [16]. This agreement established the global framework for combating climate change after 2020, promoting the transition to a low-emission economy and creating the necessity of new urban planning concepts such as the "15-Minute City" [17].

The "15-Minute City" concept is a new form of urban planning based on urban sustainability, introducing the accessibility concept and fulfilling six essential functions: housing, work, commerce, health, education, and leisure [18]. In a 15-min city, inhabitants can access any of these six functions from any point in the city within a 15-min walk or bike ride. This idea aims to reduce commuting, increase the well-being of citizens with better air quality, and reduce the emission of greenhouse gases by reducing the necessity of private vehicle use [18]. Accessibility is central to this vision, serving as a fundamental right that enables individuals to live independently and fully participate in all aspects of life [19]. It extends beyond basic mobility—focused on transporting people and goods—to ensure the broadest possible access to facilities, opportunities, and services [20]. In this sense, local authorities are responsible for ensuring and enhancing the inclusivity and sustainability of urban environments [21].

One of the key tools in achieving urban goals is the "minute city" concept, which has been embraced by various cities worldwide. Notable examples include the "15-Minute City" of Paris (Paris en Commun), the "20-Minute Neighbourhoods" of Melbourne (Plan Melbourne 2017–2050, Victoria State Government 2018), and "The Portland Plan", which also included 20-min neighbourhoods in a coalition of public and private actors. Other interesting examples of similar applications of the "minute city" concept are the Singapore's 20-min and 40-min neighbourhoods or Barcelona's superblocks [22]. Recently, several authors have conducted geospatial analysis using geographic information systems (GISs) to explore the feasibility of this concept in cities like Shanghai [23], Málaga [24], and Madrid [25].

On the other hand, many authors have addressed urban indicators related to SDGs in the past decades [26–30]. Moreover, a few of them have also studied its relationship with open data [31] and the integration of SDGs on those open data portals [32,33] highlighting the increasing importance of data accessibility in urban planning and sustainability efforts. These works underline the growing body of research that supports the practical application of the "minute city" concept while aligning with the broader objectives of urban sustainability and SDGs.

Accessibility indicators are crucial in this context, providing measurable data to assess progress toward urban sustainability goals. However, while indicators are essential to understand how the planet is performing regarding sustainability, their effectiveness relies heavily on how they are defined. Often, outdated methodologies or approaches based solely on the available data are used instead of addressing the most pressing current issues [34].

Therefore, the main goal of this paper was to identify the potentialities and weaknesses of specific areas within the city, providing valuable information for sustainable urban planning. The proposed methodology enables the evaluation of local objectives from the Urban Agenda and SDGs by using geomarketing techniques to assess urban accessibility through open data, all within the "minute city" concept framework and with high spatial resolution. Geomarketing is an integrated data system, processing software, statistical methods, and graphical representation to produce decision-useful information, using tools that combine digital mapping, graphs, and tables [35]. This paper focused on obtaining results and drawing conclusions regarding the specific facilities analysed. Key indicators related to public transport, green urban areas (GUAs), and accessibility to various public services have been evaluated.

Using geomarketing techniques in urban studies is crucial, as it allows for precise spatial analysis. While similar techniques have been successfully applied in the commercial planning and retail fields, their application in urban sustainability has been limited, often due to restricted access to high-quality open data. The proposed methodology highlights one of the main advantages of geomarketing techniques in urban planning: their ability to incorporate network analysis. This method models real-world transportation networks like roads and public transit, allowing planners to define actual travel distances and times, providing a more precise picture of how accessible different services or areas are to residents. This is particularly relevant to the "minute city" concept, where accessibility within a specific time frame is a key criterion for sustainability. By employing these tools, planners can derive more accurate results and provide better insights for decision-makers.

2. Materials and Methods

2.1. Pilot City for the Case Study

Valencia City Council, the Joint Research Centre (JRC) of the European Commission and the Universitat Politècnica de València (UPV) have reached a collaboration agreement within the Community of Practices on Cities (COP on Cities) programme [36].

The CoP-CITIES is an initiative of the European Commission, open to external stakeholders (cities and city networks, international and intergovernmental organisations, and research bodies). It builds on and brings together the ongoing work and experience in JRC pilot cities applying the Regional Policy of the European Commission (REGIO) to improve information exchange and enhance collaborative work between relevant stakeholders on urban issues [37].

Therefore, Valencia has been selected as a City Lab to explore several priority areas including the air quality, pollutants, and transport sector mobility by applying geospatial analyses to evaluate urban indicators and accessibility to city facilities [36].

Valencia is located in the Valencian Community in the eastern part of Spain. Currently, Valencia city has 792,492 inhabitants and is the third biggest city in Spain. The metropolitan area, which includes other municipalities adjacent to the city, serves more than 1,500,000 inhabitants. The city of Valencia is administratively divided into 19 districts, 88 neighbourhoods, and 606 census sections. The scope of the analysis is focused on the "Ciutat Central", considered the city's main part [38]. This subdivision contains 16 districts and 71 neighbourhoods with 757,758 inhabitants, representing 95.82% of the city's total population (Figure 1).

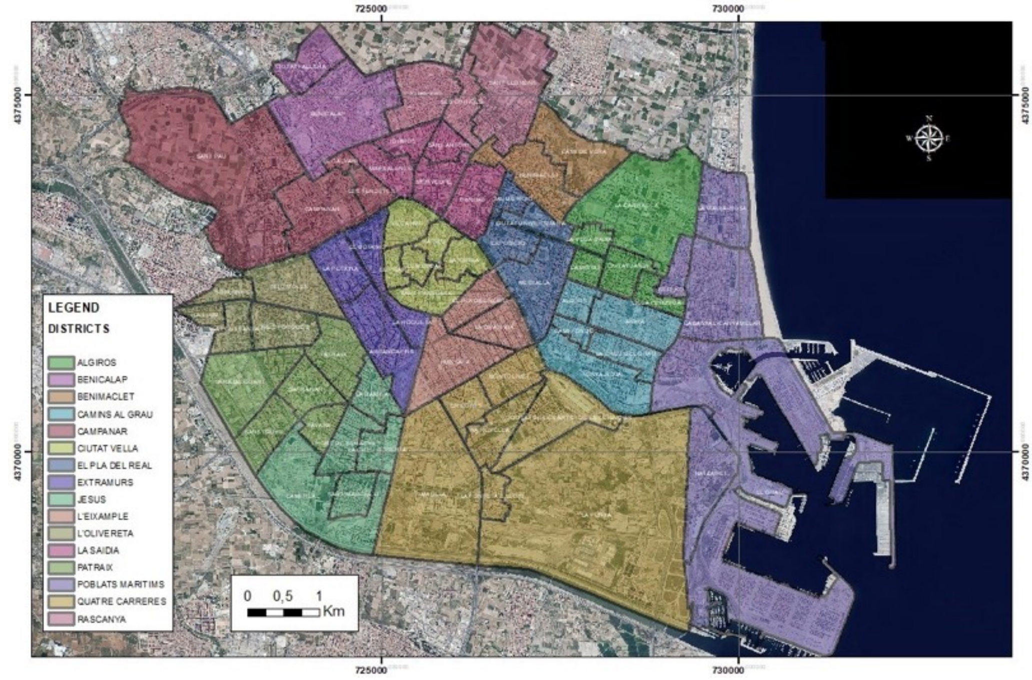

Figure 1. Geographical distribution of the neighbourhoods and districts of the city of Valencia.

2.2. *Application of the "15-Minute City" Concept to the Case Study*

Due to the COVID-19 challenges, four dimensions were incorporated into the 15-min city framework: density, diversity, proximity, and digitalisation [18]. These four dimensions have been studied in various ways according to the works compiled in [39]. However, the digitalisation dimension is difficult to approach from a GIS perspective, so it was neither developed by any of the works mentioned [40] nor in this one. It is the dimension related to the "Smart City" concept including factors such as inclusivity, resident participation, and the real-time delivery of services [14].

In this paper, the density and diversity dimensions were studied as preliminary steps before calculating the urban indicators including the proximity dimension. These two dimensions aim to provide an overview of the feasibility of Valencia's pilot case as a 15-min city. Density and diversity are discussed in Sections 2.2.1 and 2.2.2, respectively.

On the other hand, proximity is the key dimension in achieving a 15-min city. It is viewed as a temporal and spatial concept. That is, within the 15-min service areas, residents should be able to access essential services. This dimension is critical in helping cities reduce the time lost in commuting and reducing such activity's environmental and economic impacts [18]. This also helps by studying the accessibility indicators, which is the primary way to evaluate this dimension [39].

In this study, the evaluation of the proximity dimension not only considered the concept of 15-min distances like in [40,41] but also evaluated the situation of the case study regarding the SDGs. Different indicators from various sources will also be used to assess the situation of the city in question, which may also apply to other cities. This dimension is the aim of this paper. As a result, Section 2.3 (Methodology), Section 2.4, Section 2.5, Section 2.6 (Evaluation of services), and Section 3 (Results and Discussion) will analyse this dimension more broadly.

2.2.1. Density

Density is one of the most crucial dimensions of cities. In planning for sustainable cities, it is believed that it is essential to consider the optimal number of people a given area can comfortably sustain in terms of urban service delivery and resource consumption. Compact cities are fundamental for developing the six functions in a determined space [18]. Density has been evaluated by taking the residents' population density in most works compiled in [39]. This population has been deployed in urban areas [42] or in blocks or cells [43,44].

Considering the density dimension as a basis for establishing a 15-min city, it is necessary to calculate its density according to its resident population in the city of Valencia. Thus, the methodology applied was developed by Córdoba Hernández et al. [25] and is based on the classification of cities by Alguacil et al. [42] that considered the following classes:

- Inefficient city: Less than 100 inhabitants per hectare.
- 15-min city: Between 100 and 300 inhabitants per hectare.
- Dense city: Between 300 and 400 inhabitants per hectare.
- Highly dense city: More than 400 inhabitants per hectare.

The density per neighbourhood is calculated by the following equation:

$$\text{Neighbourhood density} = \text{Neighbourhood population}/\text{Area in hectares} \tag{1}$$

For this calculation, it was necessary to obtain the neighbourhoods of Valencia including their population and their boundary definition to obtain their area. The neighbourhood boundary dataset is available at the Valencian City Council Open Data Portal [43], and the population per neighbourhood is available at the Valencian City Council Statistics Office website [44].

Figure 2 shows the four neighbourhood density classifications represented in Valencia. The suburbs have a low density due to a large area of agricultural land. For these neighbourhoods, conducting an analysis differentiating between the more urban and rural areas could be interesting, as the urban part of the neighbourhood could have a considerable density compared with the rural areas.

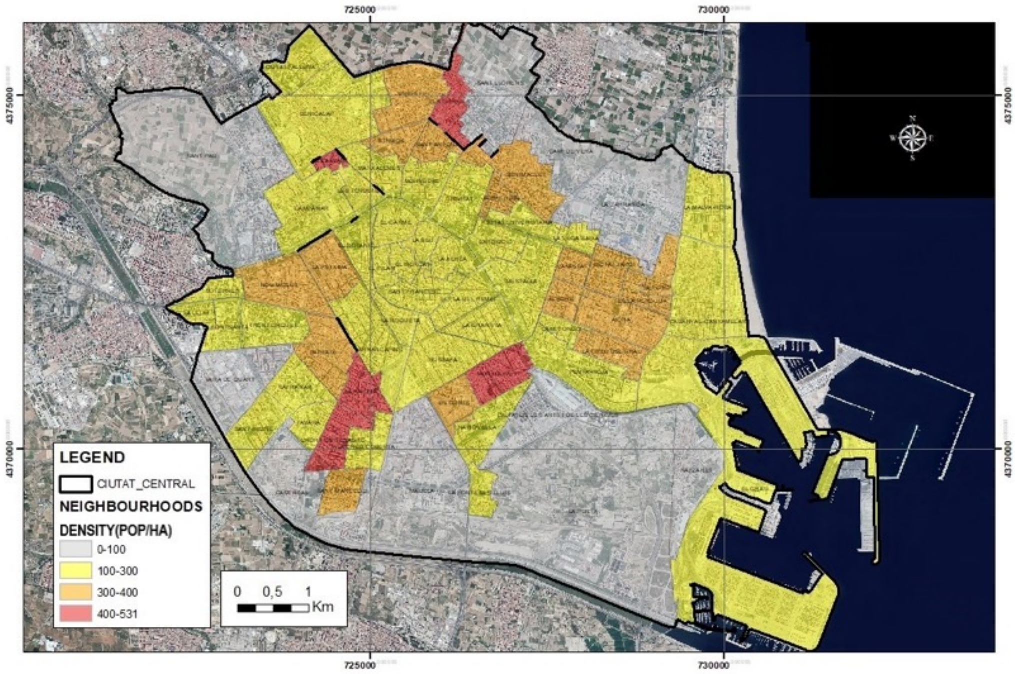

Figure 2. Geographical distribution of the neighbourhood density classification in the city of Valencia. Inefficient city (grey), 15-min city (yellow), dense city (orange), and highly dense city (red).

The rest of the neighbourhoods complied with the city density of 15-min cities (yellow neighbourhoods in Figure 2), except for some dense and very dense neighbourhoods (orange and red neighbourhoods in Figure 2). In these cases, the reduced surface area of the neighbourhood and the small area of green spaces compared with the built-up area resulted in higher densities compared with less residential areas. It should be noted that the values may vary if another type of disaggregation is selected.

The classification per number of neighbourhoods was as follows:

- Inefficient city: 10 neighbourhoods.
- 15-min city: 38 neighbourhoods.
- Dense city: 17 neighbourhoods.
- Highly dense city: 5 neighbourhoods.

This means that Valencia is a potentially viable city to reach the 15-min city target, with 54.29% of the neighbourhoods complying with the density requirement for 15-min cities. However, actions must be proposed to try to compact or decongest each area according to the characteristics of the neighbourhood.

The objective of the density analysis in this case was to determine whether the case study was feasible in meeting the population density requirements for 15-min cities.

2.2.2. Diversity

Diversity, in the case of 15-min cities, must fulfil two needs: the mixed use of neighbourhoods with residential, commercial, and entertainment components, and diversity in culture and people [18]. Diversity has been mainly evaluated by measuring the number of different amenities accessible within the defined time threshold [41,45] or by calculating a diversity-related index such as the Shannon entropy [46].

This diversity analysis aimed to reflect which neighbourhoods had more or less diversity and compare them to the density obtained in Section 2.2.1 to detect outliers before the proximity analysis.

Simpson's diversity index [47] has been considered as the diversity calculation method. This index provides insight into which neighbourhoods exhibit greater or lesser diversity and is used in other related diversity analyses such as [48].

$$S = 1 - \frac{\sum f\ (f-1)}{F\ (F-1)} \tag{2}$$

where S = Simpson's index, f = facilities from each type, and F = every facility. This will give values between 0 (no diversity) and 1 (high diversity).

The following points of interest (POIs) available at the Valencian City Council Open Data Portal [43] will be used for this calculation.

In Valencia's case study, three neighbourhoods had an index lower than 0.5 as showed in Figure 3. The "La Punta" neighbourhood obtained the lower index with 0.22. This neighbourhood was one of the most referred to as rural, and one of the lowest dense neighbourhoods classified as an inefficient city. The other two neighbourhoods were "Sant Francesc" and "Cami Fondo", with a diversity index of 0.45 and 0.49, respectively. Despite those neighbourhoods having a close index near 0.5, they were classified as 15-min city neighbourhoods in the density classification. Perhaps some actions are necessary if the nearby neighbourhoods lack some services. However, the surrounding ones had an excellent diversity index. Compared with Figure 2, the density classification did not always have a direct relationship. Still, it would be great if all the highly dense neighbourhoods reached a good diversity index to comply with the 15-min city necessities, which occurred in all of the dense and highly dense neighbourhoods, with a diversity index greater than 0.5 in all cases. Similarities have been observed in cities such as Lisbon and Oslo [48].

However, they used districts instead of neighbourhoods and different variables for POIs. It can also be seen that the central districts had a high Simpson index of around 0.8, which was the same as the central neighbourhoods of Valencia, where the resident density was more significant. It can be highlighted that Valencia's public transport diversity was better in terms of bus stops and bike renting than the other mentioned cities due to the shape of its boundaries and ease of connection. However, the underground and tram diversity should be improved to match them.

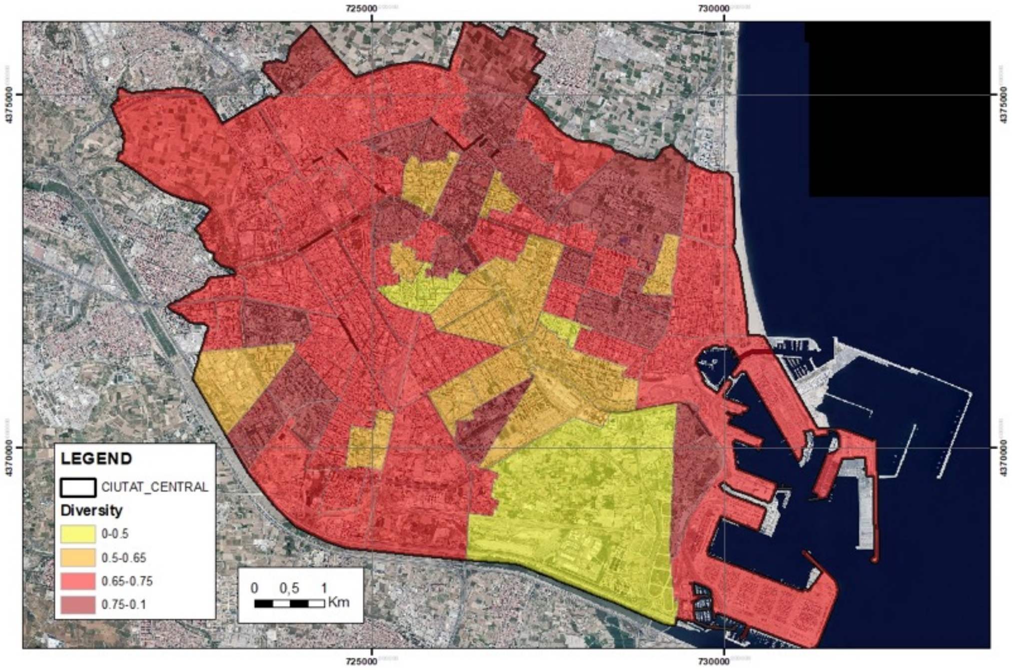

Figure 3. Geographical distribution of the neighbourhood diversity classification in the city of Valencia.

2.3. Methodology

The methodology of geospatial analysis for urban indicators was developed using GIS software and geomarketing techniques (Figure 4).

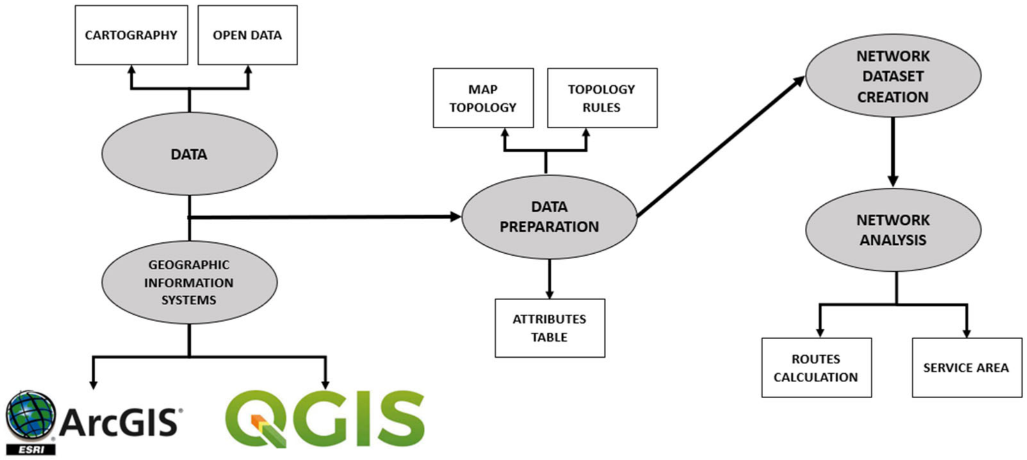

Figure 4. Methodology of the geospatial analysis for obtaining urban indicators.

Data from the Valencian City Council Open Data Portal [43] are classified into thematic layers according to the indicators, essential mapping layers, and a network layer required for network analysis. All of the data acquired should be loaded into GIS software. In this case, the software ArcMap version 10 has been used, which belongs to the ArcGIS desktop suite of products produced by ESRI.

2.3.1. Data Preparation

Next, data quality control for every layer was conducted. Initially, the layers may not always reflect the reality when superimposed on the orthophoto. This is why quality control was carried out, modifying and creating new elements as needed. The grossest errors were eliminated with map topology techniques. Additionally, a topology layer had to be created inside the network layer to check the topology rules, ensuring that streets were properly connected without overlapping any part of another line within the streets' feature class. Consequently, a connected and well-defined network could be generated.

Additionally, a quality control of the attribute tables was performed to verify the thematic accuracy and temporal accuracy. Two fields were added, one for the time and another for the distance for every network line. These fields were later used in the calculation process. As the analysis was developed based on a pedestrian network to study walking accessibility, these two extra fields were the only fields needed. The software automatically calculates the distance field due to the layer and projection configuration into the field "Shape_Length". Moreover, as previously mentioned, the analysis was based on a time concept (X-min). Consequently, a distance was given as an input, known as a "cost" value. An average person is estimated to walk 4–5 km/h [49]. However, in urban areas with large numbers of older pedestrians (e.g., in Valencia), a walking speed value of 1 m/s (about 3.5 km/h) is recommended. Indeed, a lower value of 3 km/h was chosen to be a more inclusive speed for all of the inhabitants [50]. It is important to reflect that a different data model structure may be necessary for studies based on a public transport or vehicle network.

2.3.2. Network Analysis

This section used ArcGIS Network Analyst Extension to perform spatial analyses, obtaining results for the different urban indicators. Following the network analysis workflow [51], the pedestrian network dataset, mentioned in Section 2.3.1, was added first. Then, the network analysis layer was created as a "New Service Area" layer, which defined polygons representing areas generated from a point according to a certain distance or time on the developed network [52]. Thus, three inputs were required to create the service area for this analysis: the pedestrian network layer, the facilities class, and the given distance. The facilities class comprised the city's points of interest (POIs) that were suitable for obtaining indicators. The given distance was the attribute "cost", an input field of the facilities class. The rest of the configuration was left on default. The result of this tool was the mentioned service area called the "polygon class".

This methodology has great potential for developing an accessibility analysis. This work takes advantage of this potentiality by intersecting the output polygon with a population layer to determine the number of inhabitants with the desirable accessibility for each facility or service in a determined time range. Nevertheless, it is essential to emphasise the difference between a service area buffer (also called an influence buffer) and a conventional buffer. Conventional buffers are created with a constant radius in a straight line, influence buffers depend on the network's structure. For this reason, influence buffers provide solutions reflecting real-world conditions.

2.4. Evaluation of Public Transport Accessibility to Achieve a "15-Minute City" and SDGs

The contribution of public transport to achieving a 15-min city and the different goals were evaluated using two accessibility indicators based on the population's access to different public transport services.

2.4.1. Population Without 5-Min Access to a Bus Stop

This indicator was proposed inside Valencia's Strategic Framework as part of Strategic Line 3 [53]. This Strategic Line also relates to the accomplishment of SDG 11, "Sustainable Cities and Communities", Goal 5 from the "Spanish Urban Agenda", and studying the accessibility in a particular time, which refers to the 15-min cities.

To apply this indicator, an influence buffer over the network was calculated from each bus stop in the city. Then, the generated area was intersected with a population layer by blocks to identify the number of inhabitants lacking desirable accessibility. This process helped identify potentialities for improving bus stop accessibility throughout the city.

2.4.2. Population with Simultaneous Access to Public Transport

This indicator was proposed by the local "Urban Quality Guidelines Plan" [38]. In addition to the previous indicator, it is aligned with accomplishing SDG 11, "Sustainable Cities and Communities". This indicator evaluates the population's access to the three main options for public transport: bus, underground and tram, and public bike renting. The definition of optimal access in terms of distance was based on the "System of indicators and conditions for large and medium-sized cities" [54]. The conditions were:

- 500 m distance for underground and tram stops.
- 300 m distance for bus stops and bike renting stops.

The methodology remained the same as that described in Section 2.4.1. However, in this case, every block was covered in the three different areas generated simultaneously.

2.5. Evaluation of Services Accessibility to Achieve a "15-Minute-City" and SDGs

The contribution of the accessibility of services to achieving a 15-min city and the different goals was evaluated by eight different accessibility indicators based on the population's access to these services.

Population with Desirable Access to Services

Optimal accessibility to services is vital in achieving a 15-min city including health, education, and leisure, three of the six essential functions evaluated with the following indicators. These indicators were also proposed inside Valencia's Strategic Framework as part of Strategic Line 5 [53].

The methodology remained the same as that described in Section 2.4.1 but used influence buffers of 15 min. The eight services studied and the facilities used were the same as those detailed in the Services column in Table 1.

Table 1. POIs used in the evaluation of diversity.

POI Categories	POIs
Services	Health: Hospitals and health care centres Education: Public, charter and private high and primary schools Youth centres Senior centres Social centres Sports centres: Every sports facility, indoor and outdoor Police: Police stations Libraries: Public libraries
Public Transport	Bike renting stops Underground and tram stops Bus stops (PTO)

Then, when all of the service indicators had been calculated, a synthetic map of all eight results was calculated by the blocks; this is the so-called Synthetic 15-Min index [55]. This index will yield a value between 0 and 8, evaluating the simultaneous accessibility of all services analysed.

2.6. Evaluation of GUA to Achieve a "15-Minute-City" and SDGs

The contribution of GUA in achieving a 15-min city and the different goals were evaluated using one indicator based on the population's access to GUAs by Lorenzo-Sáez et al. [56].

Population Without Desirable Access to GUA

This indicator was proposed inside Valencia's Strategic Framework as part of Strategic Line 1 [53], which relates to accomplishing SDG 11, "Sustainable Cities and Communities". The definition of desirable GUA accessibility in Section 2.2.1 was from Lorenzo-Sáez et al. [56] as well as from [57]. These conditions for the GUA accessibility needed to be fulfilled simultaneously:

- Located less than 200 m (walking distance) from a GUA larger than 1000 m^2.
- Located less than 750 m (walking distance) from a GUA larger than 5000 m^2.
- Located less than 2 km (commuting by bicycle) from a GUA larger than 1 ha (10,000 m^2).
- Located less than 4 km (travel by public transport) from a GUA larger than 10 ha (100,000 m^2).

The initial conditions and polygons of the GUAs obtained were the same as those used by Lorenzo-Sáez et al. [56]. After that, the methodology of calculation was slightly different and more precise. In this case, the influence buffers were generated from the entrances to the GUAs; additionally, the spatial resolution for the population used in this paper was more significant, representing the population by blocks instead of census sections.

3. Results and Discussion

3.1. Contribution of Public Transport Accessibility to Achieve a "15-Minute City" and SDGs

3.1.1. Population Without 5-Min Access to a Bus Stop

The population without 5-min access to a bus stop was represented with a colour scale from yellow to red intensity: yellow, 1–100 inhabitants; light orange, 100–300 inhabitants; orange, 300–500 inhabitants; dark orange, 500–900 inhabitants; and red, 900–2115 inhabitants (Figure 5). Results showed excellent overall coverage for Valencia. In fact, 611,813 inhabitants have desirable access to bus stops within 5 min of walking. This means that only 19.37% of the population does not have desirable access, achieving the objective of 80% of the population with desirable access [54].

The "Ciutat Vella" district, with the border highlighted in red in Figure 5, lacks service. There is no coverage in a large part of the district due to the characteristics of its roads, some of which are pedestrian, difficult to access for buses, or restricted to residents.

The worst access to bus stops in the city was found in the "Aiora" neighbourhood, where bus stops are located along the surrounding main streets, but none are situated within the central part of the neighbourhood (highlighted within a green rectangle in Figure 5). Thus, this geomarketing approach enabled the identification of opportunities to improve accessibility to bus stops throughout the city.

Compared with other cities in Spain, Cáceres obtained 97% [58], and in Valladolid, 100% of its inhabitants had 5-min bus stop accessibility [59]. However, these municipalities differed in their methodology with this paper. In the case of Cáceres, a conventional buffer was used over the surface instead of considering the city's network (influence buffer). In the case of Valladolid, the population by census section was used instead of the population by blocks. Therefore, these differences had a significant influence on the results. Results on the Valencia case were obtained using a greater spatial resolution, reflecting a more precise analysis.

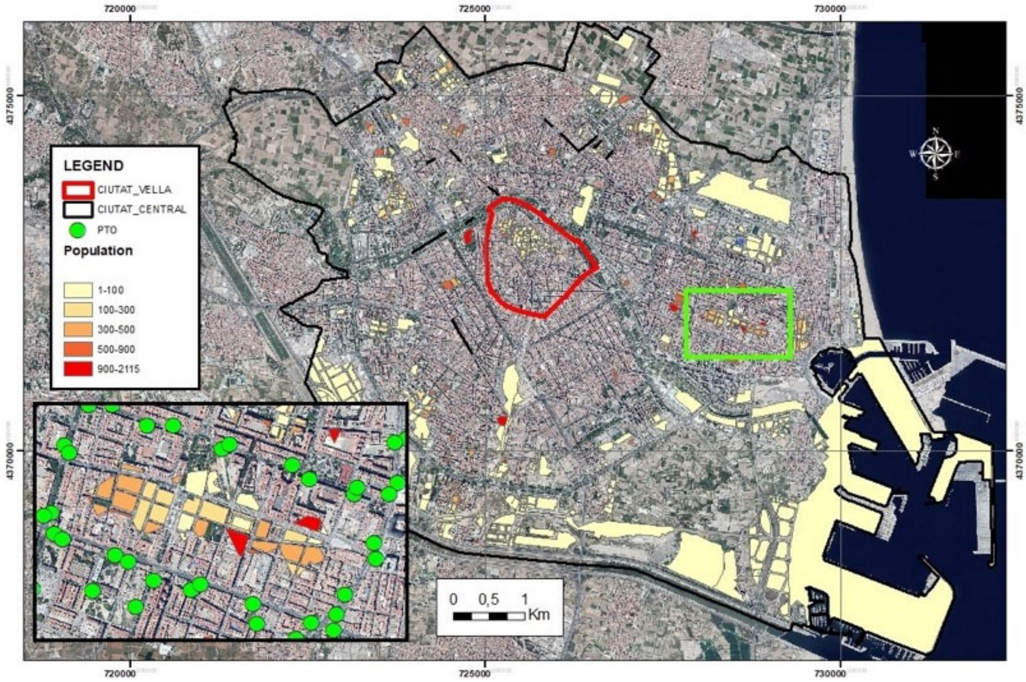

Figure 5. Population without access to a bus stop in a 5-min period by blocks.

Other 15-min city studies have analysed accessibility to bus stops, but it is difficult to find results in a range of 5 min, as this is an indicator designed for the city of Valencia [53]

In other cities, diverse results can also be observed, such as 100% accessibility within the 20-min range in Liverpool [60] or in Barcelona, where the 15-min range is used. Still, 94.2% of the accessibility was given in terms of blocks and not inhabitants [55].

These results demonstrate that the geomarketing approach presented in this paper makes it easier to detect the less well-endowed areas and improve them.

3.1.2. Population with Simultaneous Access to Public Transport

The application of this indicator showed that 430,331 inhabitants had simultaneous access to public transport in the analysed case study (Figure 6). Thus, 56.79% of the urban area population has desirable access to public transport. This means that the city must improve to achieve the objective of 80% of the population having desirable access to public transport [54].

To draw conclusions from the results of this indicator, it is necessary to examine the three types of services separately. Bike renting stops had an excellent distribution spread among the city, except for agricultural land (Figure 7). Bus stops also had a good spread, except for specific neighbourhoods such as “Ciutat Vella” and “Aiora”, as mentioned in Section 3.1.1 and shown in Figure 8. In the case of the underground and tram stops (Figure 9), the number of stops was much smaller because they involve significantly more expenditure in creating the infrastructure.

Figures 7–9 demonstrate that the lack of underground and trams was affected the most in obtaining the desired simultaneous access. In areas where the access was optimal, it can be seen that the access was also optimal in the underground and trams alone. Therefore, the rental bike and bus services were not decisive in obtaining this indicator.

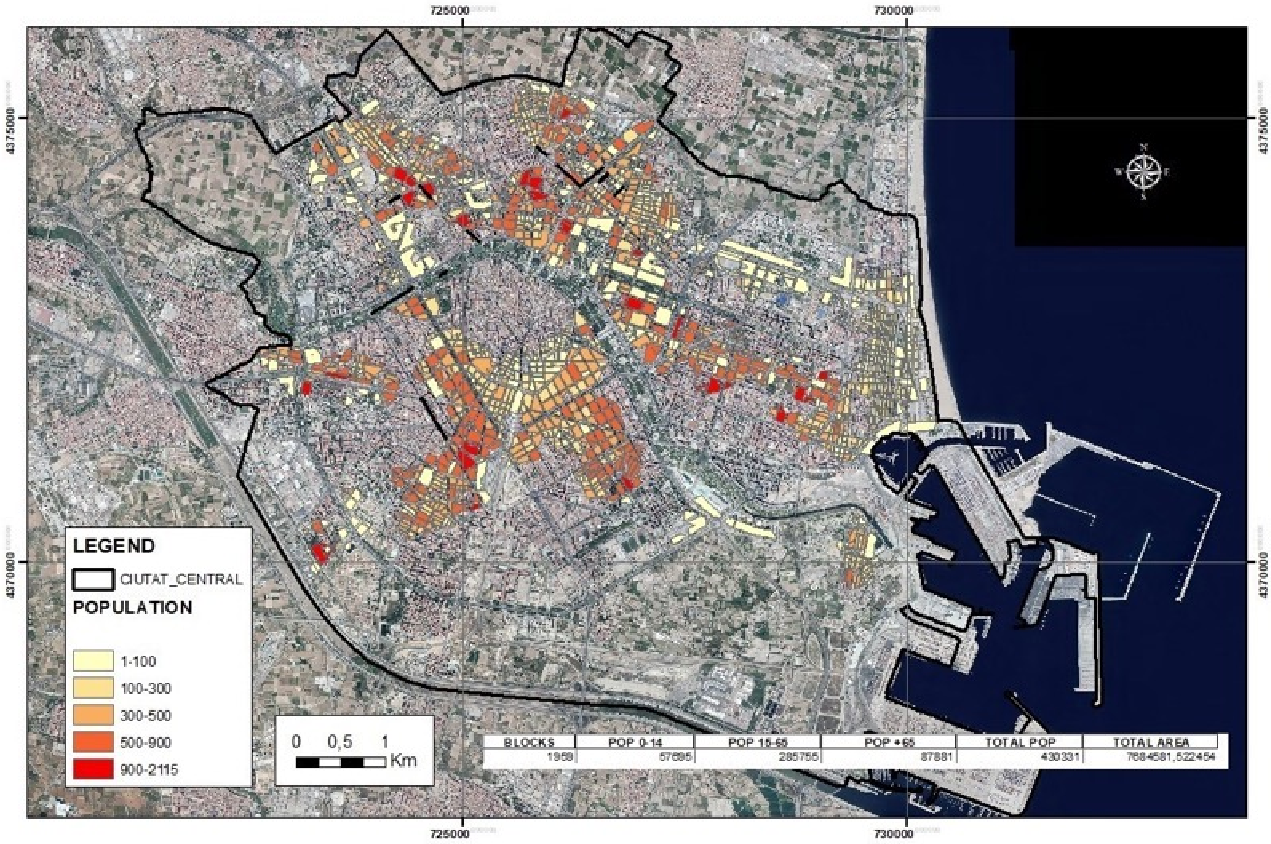

Figure 6. Population with simultaneous access to public transport service by blocks.

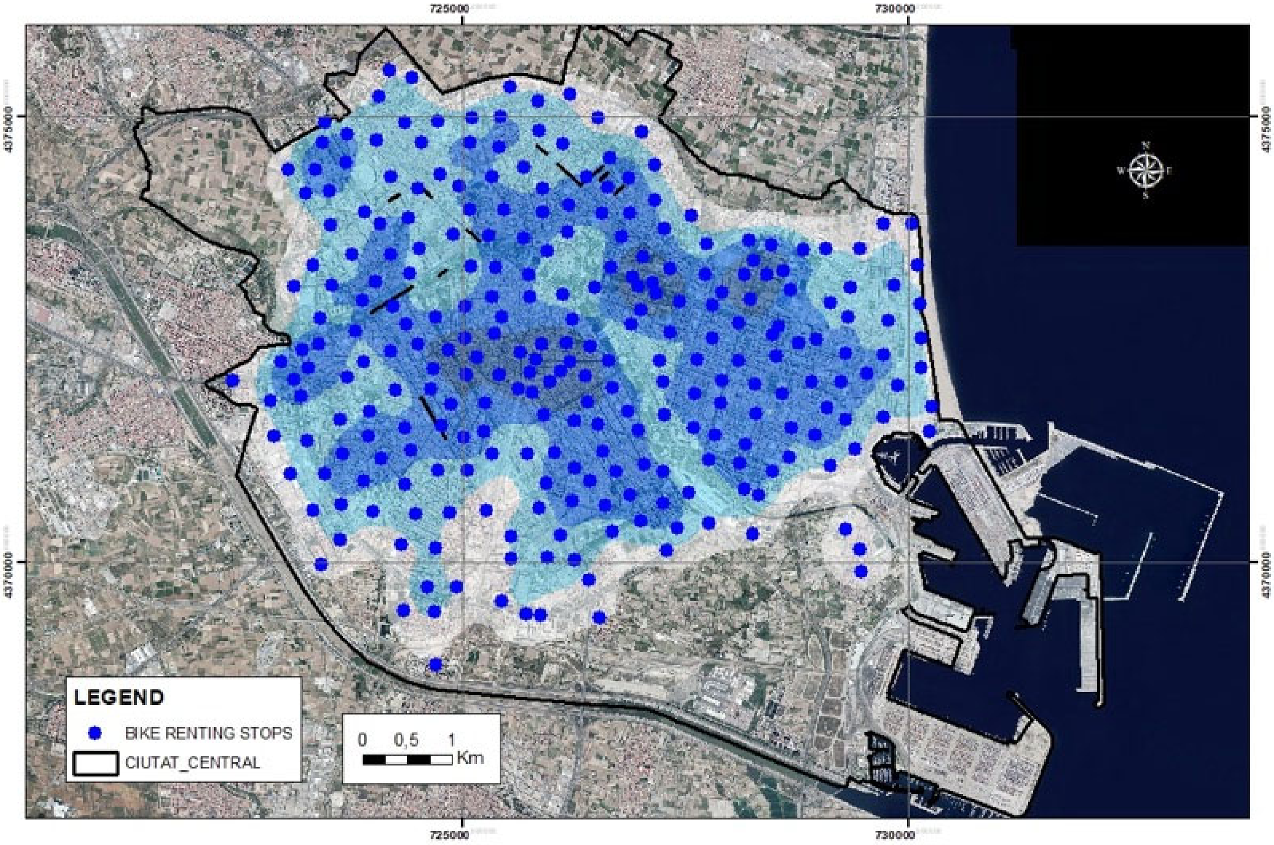

Figure 7. Determination of bike renting stops by location and corresponding heatmap.

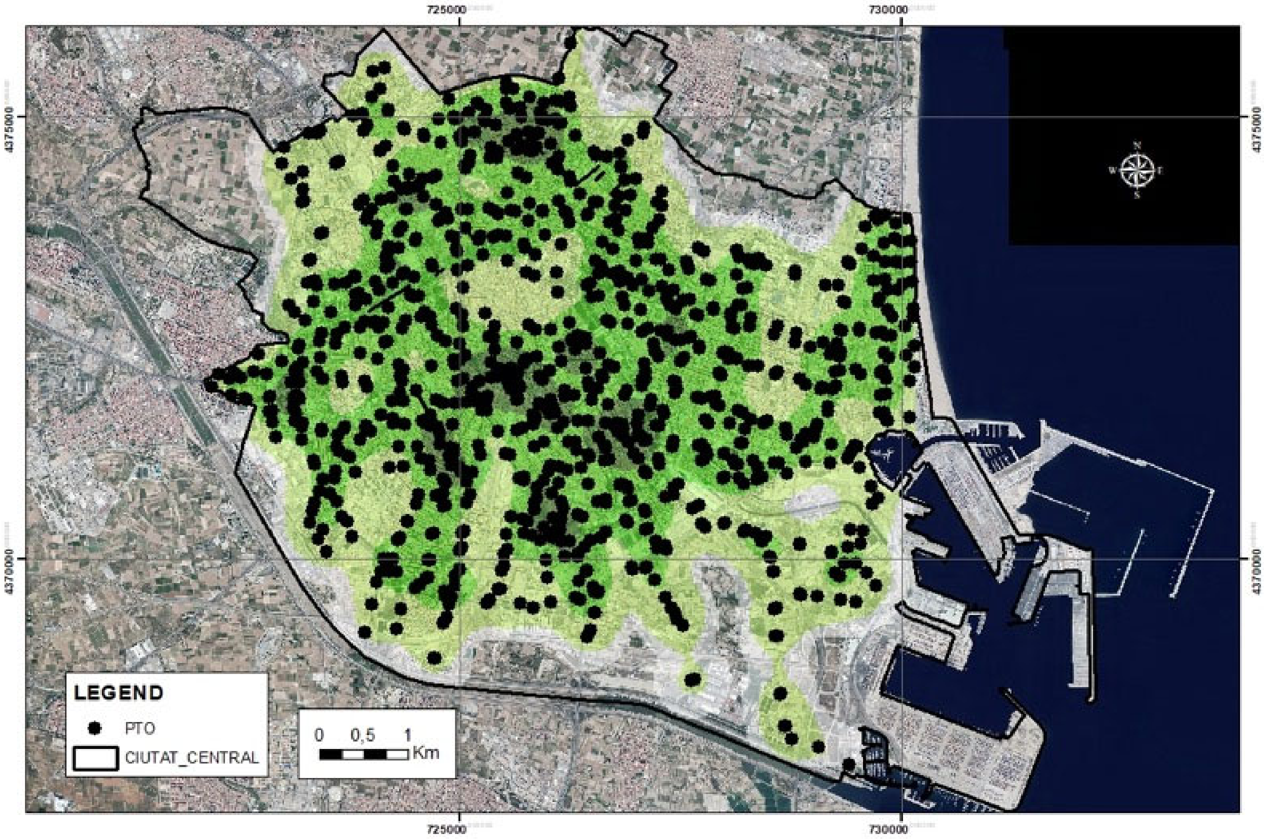

Figure 8. Determination of bus stops by location and corresponding heatmap.

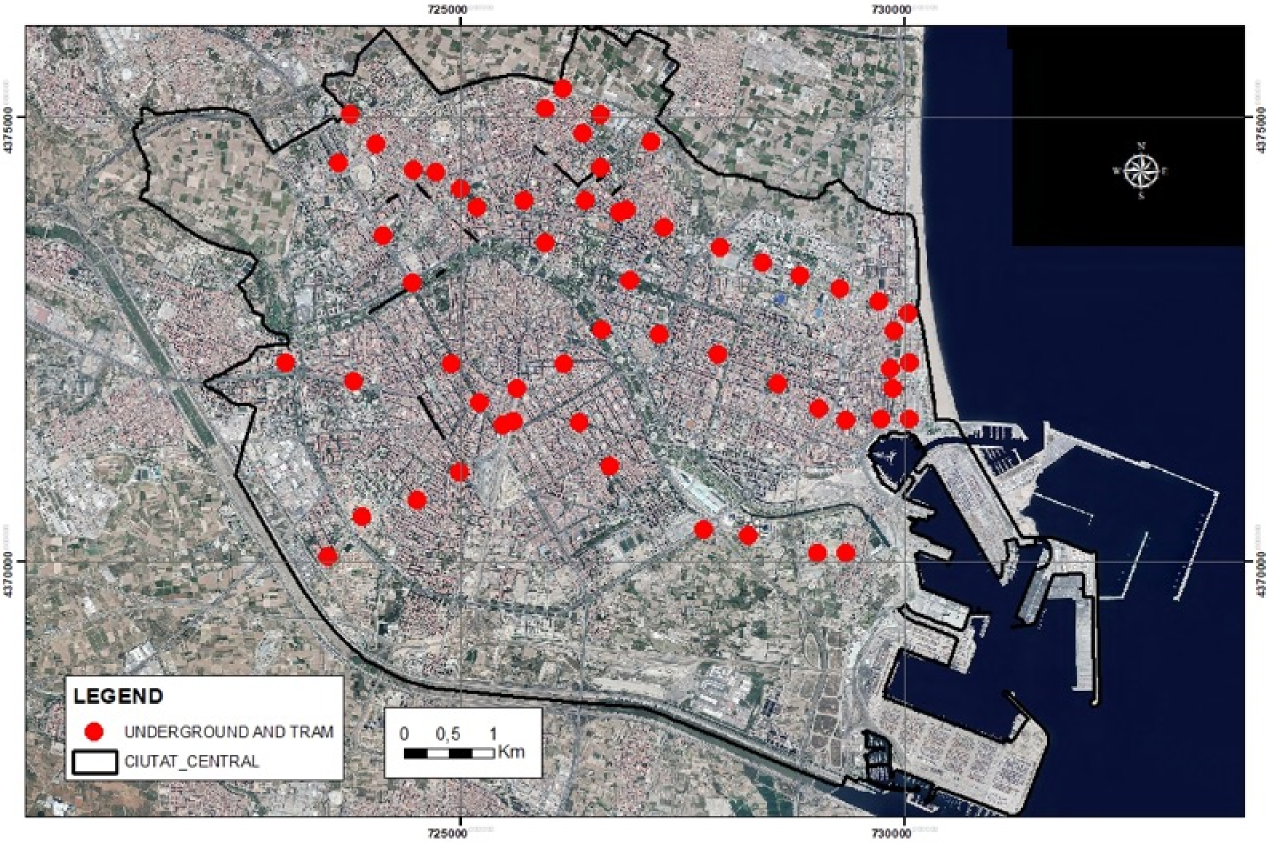

Figure 9. Determination of underground and tram stops by location.

Thus, there were worse results in areas without underground or tram stops, for instance, the districts of "Ciutat Vella" (city centre), "Quatre Carreres" (south), "Camins al Grau" (east), and "Campanar" (northwest). So far, it can be concluded that the underground and tram services exhibit the worst accessibility among the public transport services. However, these are still growing and there is plan to develop new lines [61].

In this case, the conditions for the indicator were proposed by the "System of indicators and conditions for large and medium-sized cities" [54], which is why it was difficult to find similar works to compare with the same conditions. For instance, Barcelona obtained a value close to 75% of the blocks with the five public transport services studied [55]. In that case, they did not use population, and the condition was in the 15-min range.

3.2. Contribution of Services Accessibility to Achieve a "15-Minute City" and SDGs

Population with Desirable Access to Services

The implementation of the accessibility indicators described in Section 2.5 will provide urban areas with desirable access to each type of facility. Thus, Figure 10 shows the population with desirable access to health facilities in a 15-min range. Table 2 shows the total population with desirable access and its percentage. In green, health services (87.47%), education (97.31%), senior centres (84.41%), sports centres (87.93%), and libraries (75.81%) achieved the objective proposed of more than 75% of the population with desirable access [54]. In orange, youth centres (45.89%), social centres (60.66%), and police (38.22%) did not achieve this objective. For instance, Figure 11 shows the population with desirable access to police stations in a 15-min range. It is easy to recognise the areas with a lack of access. These indicators highlight the potential improvements that could be made to achieve better accessibility and could help decision-makers define a strategy to relocate their facilities or create new ones, better investing the available resources.

Compared with other cities, as the cases above-mentioned in Section 3.1.1, Cáceres [58] obtained percentages of accessibility as follows: sports centres (60%), education (87%), and health (91%). In the case of Valladolid [59], the results were: sports centres (91.8%), education (95%), social centres (98.8%), and health (85.7%). However, as in Section 3.1.1, the mentioned differences in the methodology between the different municipalities make it challenging to compare the results.

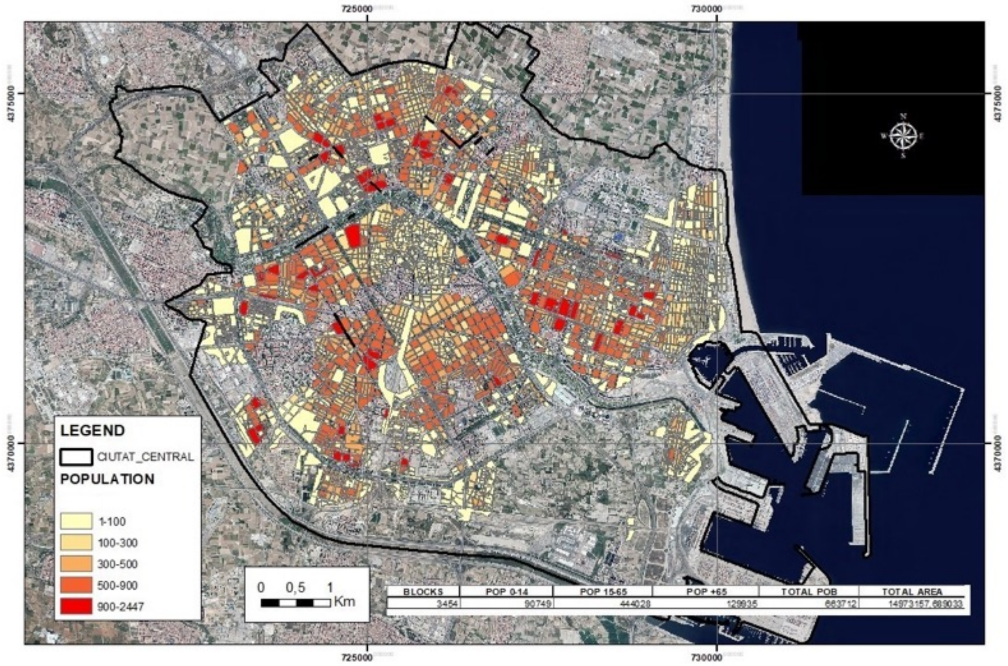

Figure 10. Population with desirable access in a 15-min range to health facilities.

Table 2. Indicators of accessibility to services in a 15-min range.

Indicator	15-min Range Inhabitants.	% of Accessibility
Health	663,712	87.47%
Education	738,347	97.31%
Youth Centres	348,226	45.89%
Senior Centres	640,449	84.41%
Social Centres	460,264	60.66%
Sports Centres	667,175	87.93%
Police	289,991	38.22%
Libraries	575,181	75.81%

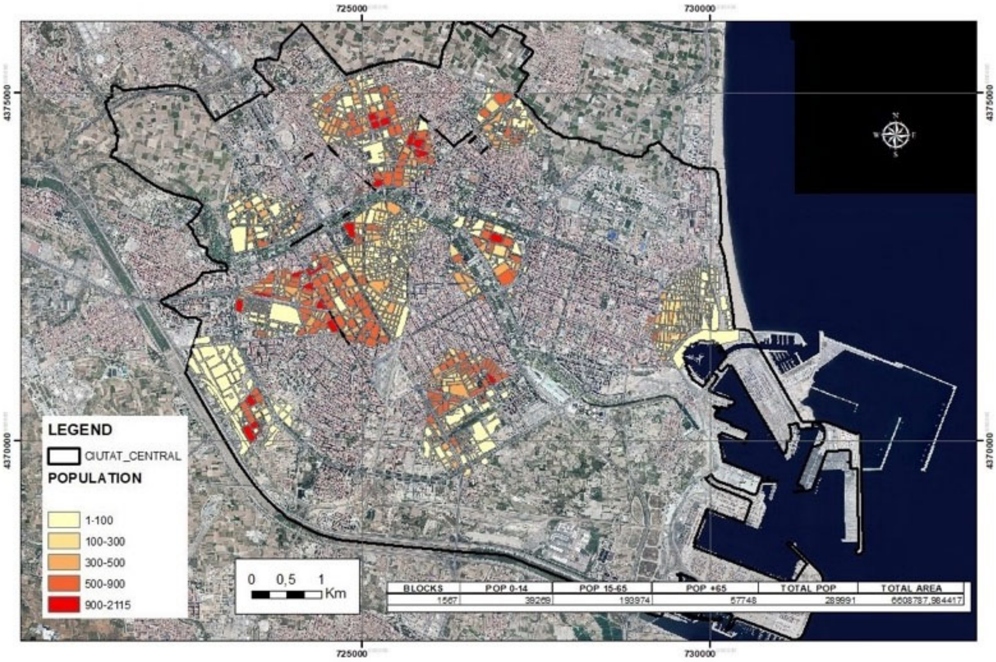

Figure 11. Population with desirable access in a 15-min range to police stations.

In these service indicators, a more in-depth analysis of each facility was required to comprehensively discuss the results of the indicator. Compared with public transport services, it was necessary to consider other variables such as the range of inhabitants' ages, service usage trends, and specific requirements. This work reflects the overall situation with the 15-min city facilities as shown in the following synthetic indicator.

These indicators enable the calculation of an index that synthesises all of them, referred to as the Synthetic 15-min index, as above-mentioned in the Sub-Section Population with Desirable Access to Services. Figure 12 shows this result for the city of Valencia. The city showed adequate simultaneous coverage, where most blocks were above 5 out of 8 services, with an average value of 5.57 accessible services per block. This can be seen in more detail in the histogram corresponding to Figure 13. This denotes good accessibility, and generally, a good distribution of services. It can be observed that the city of Valencia follows a similar pattern to that in Barcelona [55], where the peripheral areas showed lower overall accessibility. Specifically, the neighbourhoods of "La Punta" (Southeast) and "Sant Pau" (Northwest) due to their proximity to farming areas, and "Vara de Quart" (East), due to being an industrial area where it is more complicated to situate these services. On the other hand, although good accessibility was observed in the city centre, the eastern part of the historic centre stood out for its lower-than-expected accessibility. This area included blocks in the following neighbourhoods: "Sant Francesc", "El Pla del Remei", "Gran Vía", "Mestalla", and "Penya-Roja". In this area, many blocks had optimum accessibility to two or three of the services studied.

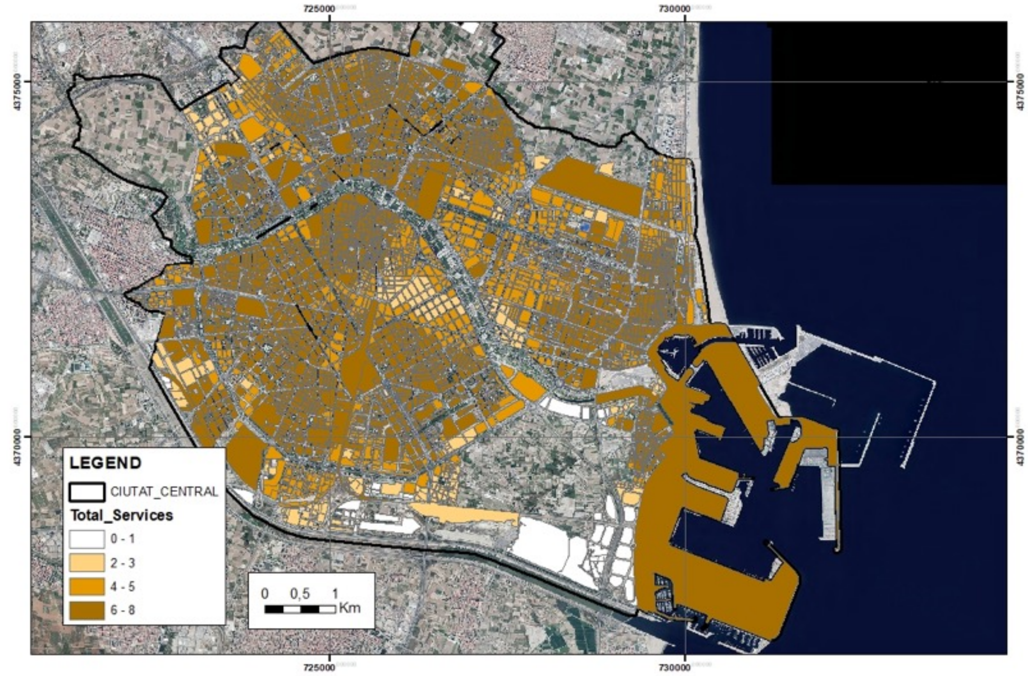

Figure 12. Optimal accessibility from the 15-min range to services by blocks. Synthetic 15-min index.

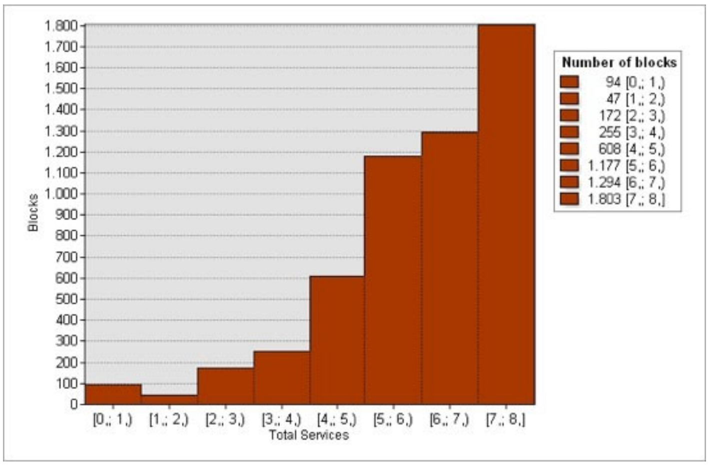

Figure 13. Histogram of the number of blocks with optimal accessibility from the 15-min range services.

This situation is also reflected in the density index calculated in Section 2.2.1, Figure 2, where some of these neighbourhoods had a lower value than nearby neighbourhoods.

Therefore, these neighbourhoods require a specific study where the available services can be expanded, either with a diversification of uses or the creation of new services. Compared with the city of Barcelona [55], it can be stated that Valencia must enhance its accessibility to approach 100% accessibility to services in the city centre. In Barcelona, at least 21 of the 24 services studied were available in the central area. Achieving full accessibility to services is vital to the city's development, especially in city centres, where more residents live, and therefore, more emissions from private vehicle use can occur.

3.3. Contribution of GUA Accessibility to Achieve a "15-Minute City" and SDGs

Population Without Desirable Access to GUA

The distribution of desirable access to GUAs and the GUA polygons within the city was assessed to identify limited access areas. The areas with desirable access to GUAs were highlighted in orange, and the GUA polygons were highlighted in green (Figure 14). The peripheral area of the city, which has plenty of agricultural land, has worse access than urban areas. However, it also obtained bad results in some areas of the centre. The neighbourhoods of "La Petxina", "Arrancapins", "Russafa", "Gran Vía", and the district of "Ciutat Vella" do not have desirable access. This is due to their old urbanism, where the area is historically residential with a considerable density of buildings and a low density of GUA. The results were pretty similar to Lorenzo-Sáez et al. [56]. Still, in this case, the areas selected as desirable access areas were more precise because the urban characteristics using the newest network and the entrance points to the GUA were considered. Figure 15 shows the potentiality of spatial resolution to obtain more precise results in the district of "Camins al Grau" (east area of the city).

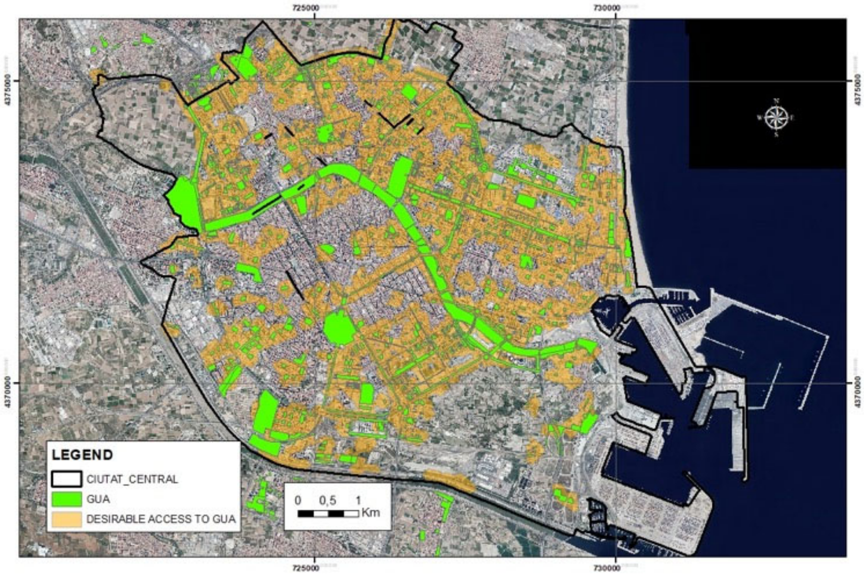

Figure 14. Areas with desirable access to GUAs.

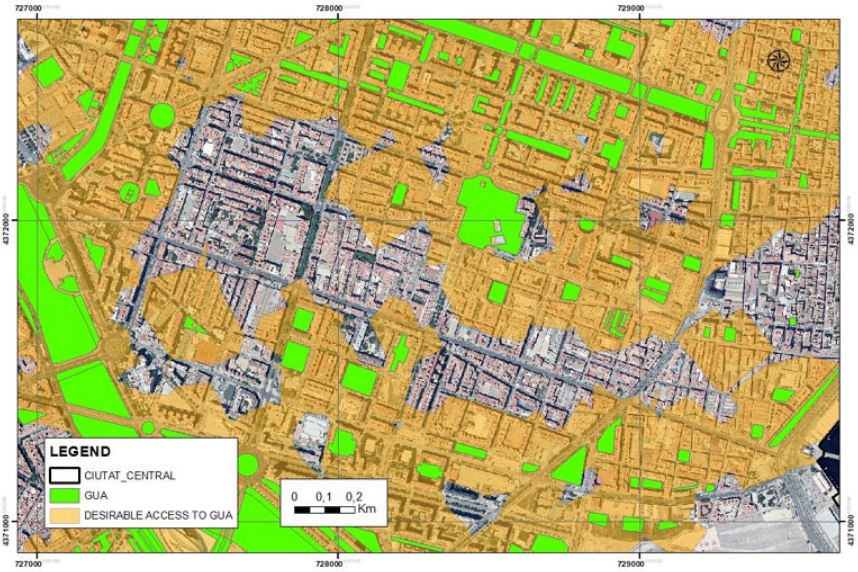

Figure 15. Areas with desirable access to GUAs. Zoomed detail of the district of Camins al Grau (east area of the city).

Figure 16 shows the population without desirable access to GUAs. The results of the applied indicator showed 445,432 inhabitants without desirable access to GUAs, which represents 58.78% of the urban area. As mentioned, this result differed from Lorenzo-Sáez et al. [56] because of the network layer and input points used. Moreover, the spatial resolution of the population was more significant, using blocks instead of census sections. Thus, the result shows that fewer people have desirable access to GUAs.

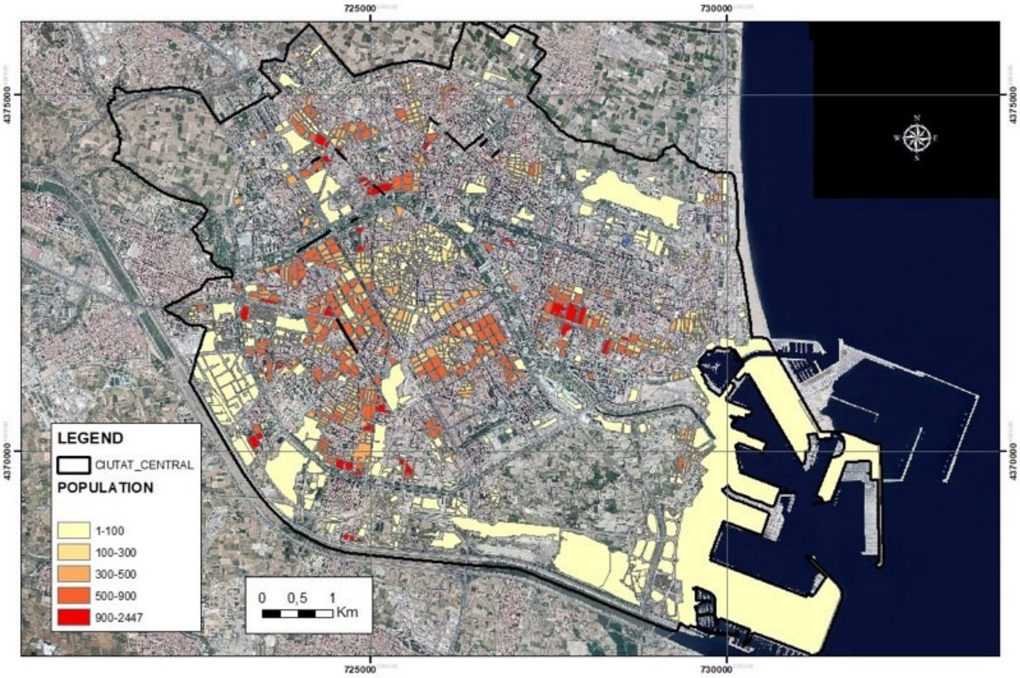

Figure 16. Population without desirable access to GUAs.

In Cáceres, the population without desirable access to GUA was 32% [58]. In Sevilla, 64% of the population resided within 500 m of a GUA [62]. In Zaragoza, more than 97% of the population lived within 300 m of a GUA [63]. However, these results are not comparable to those this paper because they differed significantly in their methodology. It has been applied to these studies with different GUA definitions than those used here (see Sub-Section Population with Desirable Access to Services).

4. Conclusions

The contribution of accessibility is crucial to the achievement of the Sustainable Development Goals (SDGs) and the urban agendas. Thus, a method was proposed and applied to four suitable urban indicators to evaluate and analyse SDG 11, "Sustainable Cities and Communities" as well as the accessibility to services of a city through geomarketing techniques. Specifically, the chosen indicators were applied to the urban area of Valencia's pilot city (Spain).

First, the indicator "Population without 5-min access to a bus stop" was used to analyse the contribution of public transport to achieving SDG 11, "Sustainable Cities and Communities". Applying this indicator to the pilot city allowed us to identify the population without optimal access to bus services. This information is crucial to decision-makers to improve the city's sustainable development and provide the same opportunities to all citizens. In addition, other public transport services (underground, tram, and shared bike renting) were included in the analysis to detect simultaneous availability so that citizens can have optimal access at the same time and have the ability to choose their preferred option.

Second, the contribution of green urban areas (GUAs) to the achievement of SDG 11 was analysed. For this purpose, the "Population with desirable access to GUA" indicator was evaluated and applied. The application of this indicator facilitated the identification of areas where a potential reclassification of land is required to create additional GUAs, ensuring that cities have the necessary quantity and optimal location. The application of this indicator to the Valencia pilot city demonstrated that only 58.78% of the population has desirable access to GUAs.

Third, the "15-Minute City" concept was analysed by studying three of their four dimensions. Density and diversity were analysed in terms of an overview of the city as a neighbourhood scale in Section 2. The diversity of services tends to increase in dense environments. A high population concentration justifies the need for a wide range of services. However, the location of the neighbourhoods can lead to the overuse of certain services while neglecting others. For instance, the "Sant Francesc" neighbourhood is a commercial area, which leaves less space for other services, and some actions may be taken, as mentioned in Section 2.2.2. Proximity was examined as a primary dimension and studied through geomarketing techniques by evaluating the 15-min range of accessibility to services per type of facility before finally obtaining a Synthetic 15-min index. This index helped to evaluate the diversity and proximity dimensions at the same time. This, together with the density, provided a more global view of the accessibility of services, such as the lack of GUAs in heavily built-up areas, as shown in Figure 15.

The methodology proposed in this study demonstrates how geomarketing techniques can be used to assess and improve the quality of urban services, leading to enhanced accessibility. It enabled the identification of services that produce suboptimal results, thereby allowing for improvements in accessibility through their effective creation or relocation. Subsequently, the proposed and tested indicators facilitated the evaluation of the achievement of the objectives and goals of Agenda 2030 as well as the goals of local administrations.

The use of GIS enables the georeferencing of indicators; furthermore, the use of geomarketing techniques is key to making the analysis faithful to the reality. As discussed in Section 2.3.2 and demonstrated in Section 3, it is important to emphasise once again the improvement observed when geomarketing techniques and networks were utilised in the accessibility analysis compared with when they were not employed. Conventional GIS buffers do not consider the real network where people travel, therefore, creating influence buffers provides solutions reflecting real-world conditions.

The assessment of urban indicators by applying this methodology is very suitable and easy to replicate for cities with a smart city platform and open data infrastructure. Although these indicators have room for improvement, the most necessary enhancement is the data quality. This will hopefully encourage administrations to dedicate more resources to acquire better data, focusing on thematic and positional accuracy and striving to achieve the highest spatial and temporal resolution possible. This will improve the accuracy of the analytical results.

The results derived from these spatial analyses provide valuable insights to assist in the administration's decision-making process, helping to mitigate the effects of climate change, such as the deterioration of air quality, by potentially reducing trips in private vehicles. Nevertheless, it is essential to continue developing similar works because cities have many aspects that require improvement to comply with every goal and enhance the overall quality of life. Urban planning strategies offer actionable recommendations to improve accessibility, comfort, inclusion, and sustainability [64].

As demonstrated in the analysis of accessibility indicators, certain areas did not meet the desired accessibility standards. Therefore, the "Facility Layout Strategy Based on Reachability and Share" strategy can be applied. New facilities can be strategically introduced to address this issue. For instance, Figure 17 highlights how adding a facility in the "Aiora" neighbourhood (black dot highlighted by a green box) would improve accessibility, extending it to an additional 47,002 inhabitants, thus increasing the total population with desirable accessibility to police stations by over 6% (from 38.22% to 44.41%). This method shows the potential for urban planning to enhance accessibility across various city areas, and future work could explore how additional facilities might impact other locations.

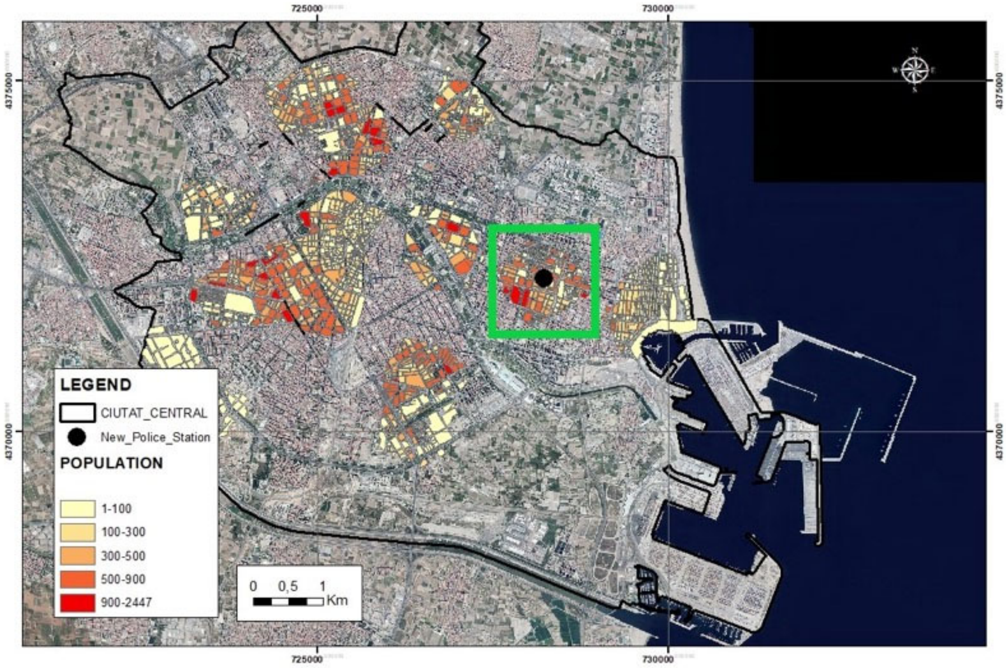

Figure 17. Population with desirable access in a 15-min range to police stations by adding a new one.

Other strategies suitable for application in future research are:

a. Layout strategy with mixed functions: One of the objectives of the 15-min cities is the creation of mixed-use facilities, which promotes more efficient facility use and reduces travel distances, leading to lower emissions. Creating these centres would significantly reduce the need for multiple trips by concentrating services in one location. An alternative methodology to the one used in this paper would calculate 15-min areas based on resident communities, as proposed by Li et al. [64], rather than from facilities, offering a complementary approach depending on the analysis objective.

b. Differential layout strategy for population structure and activity features: Different age groups have varying needs, so tailored strategies must be developed to ensure that services meet the specific demands of each demographic. This can be achieved by weighting facilities based on population type, as described in [65]. While this paper did not conduct an in-depth analysis of the population by age, the accessibility maps (Figures 6, 10 and 11) showed the population distribution across three age groups: 0–14, 15–65, and +65. Future work could expand on this by incorporating detailed population studies into the analysis.

These strategies illustrate how urban planning can be optimised to improve a city's accessibility and liveliness. As cities evolve, further analysis and the development of such methods will be crucial in creating inclusive, sustainable, and comfortable environments for all residents.

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