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Original Research Article

A Quantitative Model of the City in 15 Minutes for Decision-making

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ABSTRACT

Addressing challenges like urban sprawl, pollution, and heat islands is imperative in contemporary urban contexts. Understanding urban mechanisms and prioritising proximity and sustainable mobility is crucial for meeting citizens' needs. This study presents a quantitative model with 21 composite indicators, aligning with the 15-minute city theory's dimensions (Education, Health and Social Welfare, Leisure and Culture, and Supply) to measure resource accessibility. Focused on Valencia, the analysis of its 70 neighbourhoods reveals significant disparities in indicators, mainly due to geographical distribution. Peripheries consistently score lower, while city centres and high-status neighbourhoods score higher. It underscores the importance of targeted interventions for equitable access to resources across urban areas.

KEYWORDS

Chrono-urbanism, Smart cities, Open data, Geospatial analysis, Multivariate analysis, Composite indicators.

INTRODUCTION

Many modern cities carry on the legacy of 20th-century rationalist urbanism, resulting in a widespread reliance on individual cars [1, 2], urban sprawl towards outlying residential zones [3], and a lack of preparedness for rising populations [4]. As a result of such planning, these cities face a host of issues related to resource depletion, pollution [5], heat islands [6], and social disparity [7].

Various international and local institutions have initiated actions in response to the pressing challenges facing urban environments [8]. The United Nations (UN) Sustainable Development Goal 11 underscores the imperative to "Make cities and human settlements inclusive, safe, resilient, and sustainable." As highlighted in the 2022 UN-Habitat World Cities Report [9], urgent action is essential to address the intersecting climate change and biodiversity loss crises, emphasising the critical need to forge sustainable urban futures. Urban areas shoulder a significant burden, accounting for an estimated 67−72% of global greenhouse gas emissions, as reported in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report [10]. This substantial contribution predominantly originates from sectors like transportation, construction, and manufacturing industries, which are heavily concentrated within cities and their metropolitan regions [11].

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In response to contemporary urban challenges, emerging concepts within theoretical urbanism have gained prominence. Particularly notable is the concept of chrono-urbanism, which has garnered significant attention in recent years due to its emphasis on reducing commuting time and improving access to essential amenities in residents' daily lives. At the forefront of this theory is the notion of the 15-minute city, pioneered by Carlos Moreno in 2016 [12]. The 15-minute city proposes the development of urban areas where vital amenities are reachable within a 15-minute radius, advocating for a sustainable urban model that fosters community interaction and cohesion among residents. In his 2020 article titled "Introducing the 15-Minute City: Sustainability, Resilience, and Place Identity in Future Post-Pandemic Cities" [13], Moreno lays out the theoretical underpinnings of this concept. He emphasises six fundamental services for urban life: housing, employment, education, healthcare, leisure and culture, and local commerce.

The concept of the 15-minute city is not fixed but adaptable, accommodating variations in city size and topography. Over the years, efforts have been made to quantify different iterations, such as the 5-10-15… minute cities, collectively termed x-minute cities [14]. This model presents a promising departure from traditional rationalist urban planning, offering a pathway towards future cities with net-zero greenhouse gas (GHG) emissions. Central to this concept is the reduction of travel distances and resource consumption, achieved through proximity-based planning [15]. Such an approach can diminish reliance on cars and facilitate the transformation of urban topologies towards net-zero emissions [16]. The x-minute city model, as endorsed by the European green cities transition [17], explicitly discourages dependence on private motorised vehicles, which currently contribute 72% of GHG emissions in the transportation sector [18]. A primary objective is to promote alternatives such as increased bicycle usage, public transportation, and pedestrian-friendly environments. Additionally, the model advocates for localised consumption and production, aiming to reduce reliance on centralised production hubs and the associated GHG emissions from packaging and transportation, which collectively contribute approximately 20% of global GHG emissions [19].

The COVID-19 pandemic has significantly enhanced the relevance and applicability of this theoretical model. Cities such as Paris and Melbourne have already taken proactive measures towards achieving this objective through initiatives like "Ville du quart d'heure" [20] and "Plan Melbourne" [21]. A notable case study is the city of Valencia, which since 2020 has embraced this concept and initiated urban planning strategies aimed at positioning itself as a leader in the 15-minute city theory through its Missions València 2030 program [22]. The primary objective of this initiative is to achieve net-zero greenhouse gas (GHG) emissions by 2030. Furthermore, Valencia has been designated the European Green Capital for 2024 [23], further emphasising its commitment to sustainability. Valencia will be the focal point of this study for these compelling reasons.

The government's actions and need to measure changes have led to the development of various indicators that allow the quantification of accessibility in the x-minute cities. Several studies have proposed the development of metrics related to city sustainability [24, 25], cycling [26, 27], walkability [28], pedestrian-friendly environments [29], and the assessment of accessibility to resources in cities based of different mobility [30] and accessibility scores [31]. Nevertheless, the methodology proposed in this analysis integrates multiple straightforward indicators of accessibility and availability into a composite indicator for each essential resource type accessible to the population daily. Furthermore, the study will exclusively utilise open data sources and free software tools, emphasising the importance of information sharing for collective societal progress. Additionally, a standardised methodology will be developed for the extraction, transformation, and loading (ETL) of data, with a focus on adaptability to evolving urban contexts and potential applicability to comparative studies in different cities.

MATERIALS AND METHODS

Implementing the methodology presented in this article necessitates undertaking prior and comprehensive work in data extraction, transformation, and loading (ETL), focusing on open data principles. Subsequently, various tools are employed to calculate distances based on city network analysis. Four simple indicators measuring distances and availability of amenities are proposed, which will be weighted and normalised into a final composite indicator considered a key performance indicator (KPI). This process will be repeated for the 21 different typologies of amenities considered in the study (**Table 1**).

Table 1. Description grouping of resources for the calculation of composite indicators

Indicator	Description	Dimension
K1	Early Childhood Education Centres	Education (EDU)
K2	Primary Schools	
K3	Secondary Schools	
K4	Vocational Training Centres	
K5	Adult Education Centres	
K6	Health Care Centres	Health and Social Welfare (HSW)
K7	Social Resources for Young People	
K8	Social Resources for the Elderly	
K9	Social Resources for the Entire Population	
K10	Pharmacies	
K11	Municipal and Special Markets	Supply (SUP)
K12	Food Products	
K13	Supermarkets	
K14	Household Products	
K15	Cultural Products	
K16	Other Products	
K17	Food Services	Leisure and Culture (L&C)
K18	Cultural Services	
K19	Sport Activities	
K20	Museums, Libraries and Theatres	
K21	Parks and Green Areas	

Data

The study relied upon a comprehensive collection of 64 diverse and sourced datasets during its development. The location of centres belonging to the dimension of Education has been extracted from the Conselleria d'Educació, Cultura i Deporte de la Generalitat Valenciana **[32]**, with a total count of 667 centres. The centres related to the dimension of Health and Social Welfare have been obtained from the CKAN API of the open data portal of the Valencia City Council **[33]**, a total of 617. The rest of the resources belonging to the dimensions of Leisure and Culture and Provisioning have been extracted from the Python Open Street Map API (osmnx) **[34]**, with quantification of final locations of 1,268 and 3,189, respectively.

For the four dimensions of the 15-minute city urban theory, 21 typologies of amenities considered social determinants of well-being have been identified. Table 1 presents the grouping of indicators within the dimensions of "education" (EDU), "health and social welfare" (HSW), and "leisure and culture" (L&C), each comprising five indicators, while the dimension of "supply" (SUP) encompasses six indicators.

Distance calculation

The first step to compute the 21 KPIs involves estimating the closest intersections of the city's portals, followed by calculating isochrones. Lastly, the shortest path is determined to weigh the distances to the 21 resource typologies' locations.

Isochrone calculation. An isochrone is defined as a line connecting different points reached simultaneously from a common origin, forming an area of influence for that point [15]. It can be expressed as $I(\tau, \lambda)$, where τ represents the origin point and λ the maximum range time. Each intersection is interpreted as a central node from which a subgraph is obtained with its nearest neighbours reached in a maximum time interval of 15 minutes, travelling at an average speed of 4.5 km/h on foot. The most distant neighbouring nodes form the perimeter of the area of influence that delimits the isochrone.

Shortest path. When interpreting the city as a graph, only the information contained within the subgraph comprised by the isochrone associated with λ is considered to calculate the distances from an intersection i to the different resources of the city (Figure 1). Dijkstra's algorithm [36] calculates the approximate distance between the intersection and its isochrone locations by finding the shortest path. The intersection closest to the portal is the initial vertex, the intersection closest to the resource location is the final vertex, and the lengths (m) of the edges representing the streets are the weights of the graph. All the nodes and edges that make up the shortest path are traversed to get from one vertex to another. Finally, the total distance between the two locations is obtained by adding the weights of the edges.

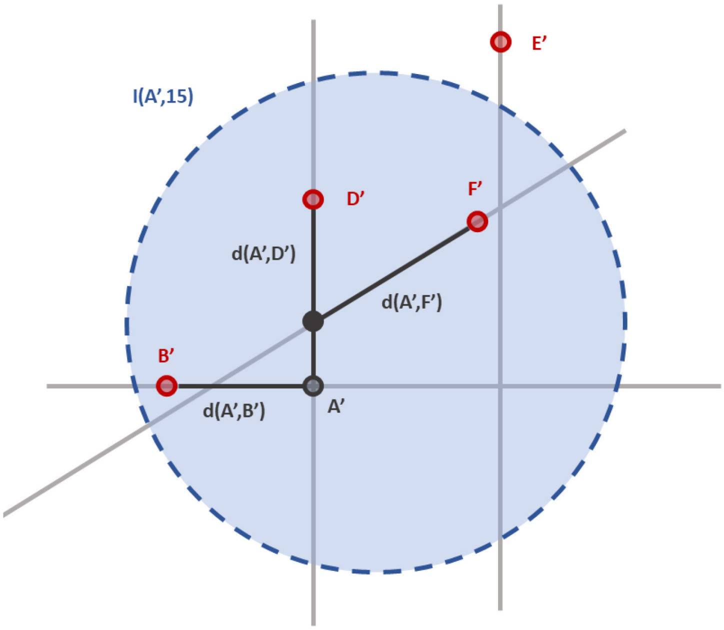

Figure 1. Calculation of distances for the shortest path from A' to all resources (B', C', D', F') included in the isochrone I(A', 15)

Calculation of simple indicators

The distances to each resource intersecting with their 15-minute isochrone in the 21 established categories were obtained for the intersections closest to the city's portals. Then, the values in meters of these distances are converted into four simple indicators based on the concepts of accessibility (a_1 and a_2) and availability (d_1 and d_2). Accessibility is the measure of time to access resources, and availability is the quantification of available resources.

- a_1: Average time to access resources from the portal of each neighbourhood.
- a_2: Minimum access time to the resources from the portals of each neighbourhood.
- d_1: Proportion of portals in a neighbourhood with access to at least one resource.
- d_2: Average count of resources available for the portals in each neighbourhood.

Calculation of composite indicators

Based on the four simple indicators calculated previously, the 21 KPIs of the study are formed. The criteria chosen for the development of the different phases were taken from the reference sources for the creation of composite indicators proposed by the Organization for Economic Cooperation and Development (OECD) [37] and the World Health Organization (WHO) [17].

Normalisation. The treatment of simple indicators in the normalisation process allows for solving problems related to the existence of different units of measurement in the original data or ranges of variation. The choice of a methodology depends on each indicator's intrinsic characteristics and the study's appropriateness. The WHO Urban Health Index (UHI) [19] proposes a min-max normalisation to constrain each simple indicator's value between 0 and 1.

Weighting and aggregation. Equal weighting is applied for the four simple indicators [37] so that the two dimensions of accessibility and availability maintain an equal balance. In future analyses, it would be of great interest to have feedback from citizens and institutions to apply weights more adapted to real needs. The aggregation chosen for the four simple indicators is the weighted geometric mean, given its non-compensatory nature and the possibility of an easy modification in the methodology in case of changes in the assigned weights. Moreover, this is the procedure the WHO recommends when creating the Urban Health Index [38]. With the weight assigned to each of the four accessibility/availability indicators denoted as w_q, the formula is:

$$IC_i = \prod_{q=1}^{Q} (I_{q,i})^{w_q} \tag{1}$$

Where $I_{q,i}$ is the normalised value of I for the indicator q as $q = 1 \dots Q$ and $i = 1 \dots N$, following $\sum_{q=1}^{Q} w_q = 1$ and $0 < w_q \leq 1$. In this instance, all weights are set at 1/4 to ensure equity [38]. Therefore, the calculation of each of the 21 composite indicators is determined by:

$$K_i = a_{1i}^{\frac{1}{4}} \times a_{2i}^{\frac{1}{4}} \times d_{1i}^{\frac{1}{4}} \times d_{2i}^{\frac{1}{4}} \quad \forall i \in \{1,2,\dots,21\} \tag{2}$$

Local spatial autocorrelation Anselin's I

Local measures offer a more in-depth analysis of spatial observations by examining the relationships between each observation and its nearby surroundings rather than presenting a summary statistic for the entire dataset. This approach enables a deeper understanding of the spatial structure of the data, as it allows for identifying areas with unusual concentrations of values.

Anselin's I is a type of local indicator of spatial association commonly used to assess whether the spatial clustering of variable values is significantly high, identifying cases where the value of an observation and the mean of its neighbours are similar, with High-High (HH) and Low-Low (LL) values or dissimilar with Low-High (LH) or High-Low (HL), compared to what would be expected by chance. The statistic is calculated using the following formula:

$$I_i = \frac{(y_i - \bar{y})}{\frac{\sum_i (y_i - \bar{y})^2}{n}} \times \sum_j w_{ij} \times (y_j - \bar{y}) \tag{3}$$

Where $\frac{\sum_i (y_i - \bar{y})^2}{n}$ represents the variance of the data distribution, $(y_i - \bar{y})$ − the value of observation i standardised by subtracting its mean, w_{ij} − the weight for the pair of observations i and j, and n is the number of observations.

València as a case study

The analysis in this study will focus on the 70 neighbourhoods comprising the Ciutat Central of València, Spain, which accommodates 96.3% of the total population. With 830,000 inhabitants, Valencia ranks as Spain's third most populous city. It is characterised as a polynuclear city, encompassing an area of 98.78 km^2. Its neighbourhoods display notable heterogeneity, each possessing unique realities and specific needs. In recent years, Valencia has emerged as a city at the forefront of sustainability and innovation. It is evidenced by its inclusion in the Urban Planning and Social Welfare SDEWES Index [39], which ranks 36th out of 120 benchmark cities. This index incorporates composite energy, water, and environmental indicators. Valencia's commitment to sustainability is also underscored by its recognition as the European Green Capital for the year 2024. Consequently, a thorough examination and in-depth analysis are warranted to account for these distinct characteristics.

RESULTS

Once the 21 KPIs of the study have been defined and calculated for each 70 Ciutat Central de Valencia neighbourhoods, their behaviour is analysed using chloroplast maps. In order to give statistical significance to the spatial behaviour presented by the 21 indicators in the city's neighbourhoods, the classifications of local spatial autocorrelation according to Anselin's *I* statistic are shown in the different dimension maps.

Several neighbourhoods exhibit distinctive characteristics in the education dimension (**Figure 2**). La Fonteta de Sant Lluís, Ciutat Fallera, Sant Isidre, Sant Pau, and Ciutat de les Arts are notable for their low values. Conversely, neighbourhoods situated in the city's urban core, such as El Carme, El Pilar, and El Botànic, demonstrate the highest results. The anomalous behaviour observed in indicator K5 is particularly noteworthy, with positive peaks visible in neighbourhoods like Natzaret and La Malva-Rosa, located in the eastern periphery.

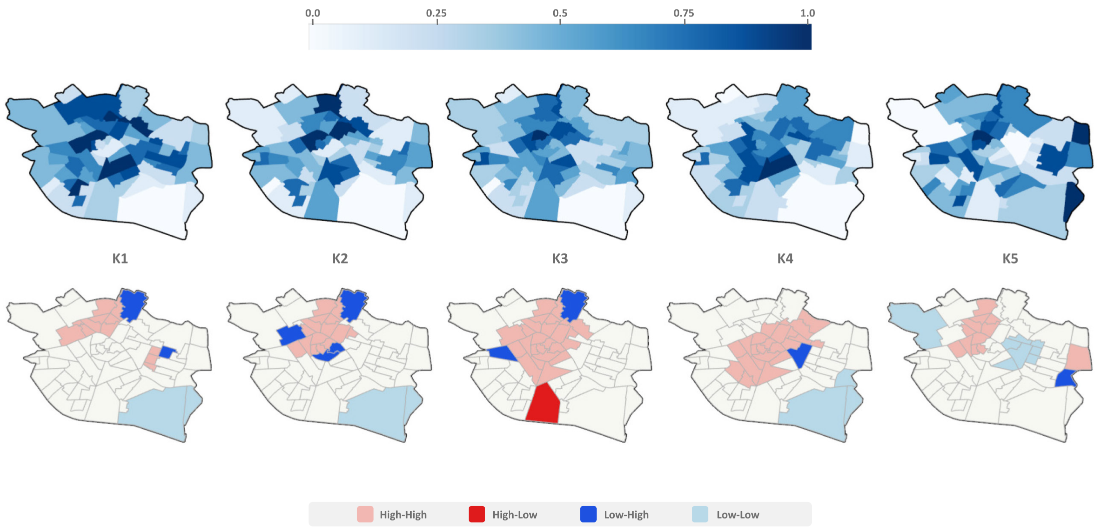

Figure 2. Indicators of the education (EDU) dimension and its local spatial autocorrelation

Concerning the health and social welfare dimension (**Figure 3**), several neighbourhoods stand out for their performance. La Fonteta de Sant Lluís, La Llum, Soternes, and Fontsanta exhibit the poorest results, while El Pilar, La Creu del Grau, and L'Illa Perduda demonstrate the highest scores. Notably, the latter two neighbourhoods, not typically part of the urban core, have achieved exemplary outcomes. Additionally, the performance of indicator K6, about healthcare, is notable, with neighbourhoods like El Pilar or El Mercat, despite achieving good overall results, scoring approximately 0.5 out of 1. Furthermore, the Natzaret neighbourhood deserves mention for its outstanding performance in the indicator of social resources for young people (K7).

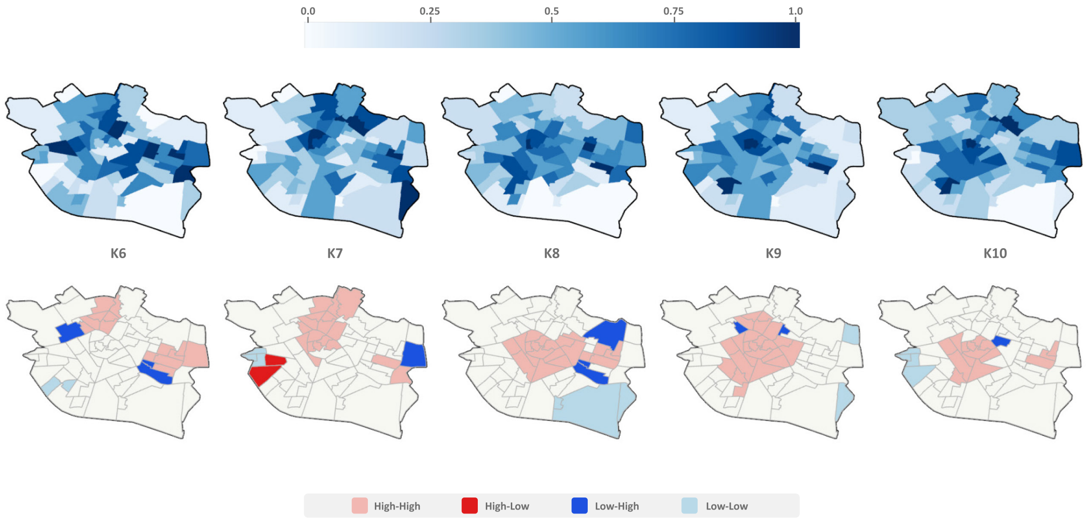

Figure 3. Indicators of the health and social welfare (HSW) dimension and its local spatial autocorrelation

Significant disparities among neighbourhoods are evident in the supply dimension (Figure 4). Over 14 neighbourhoods have average scores below 0.5 on the indicators, with La Punta, La Fonteta de Sant Lluis, La Llum, and Sotemes being notable for their lower scores. Conversely, the neighbourhoods with the highest results include El Mercat, Benimaclet, and Sant Francesc.

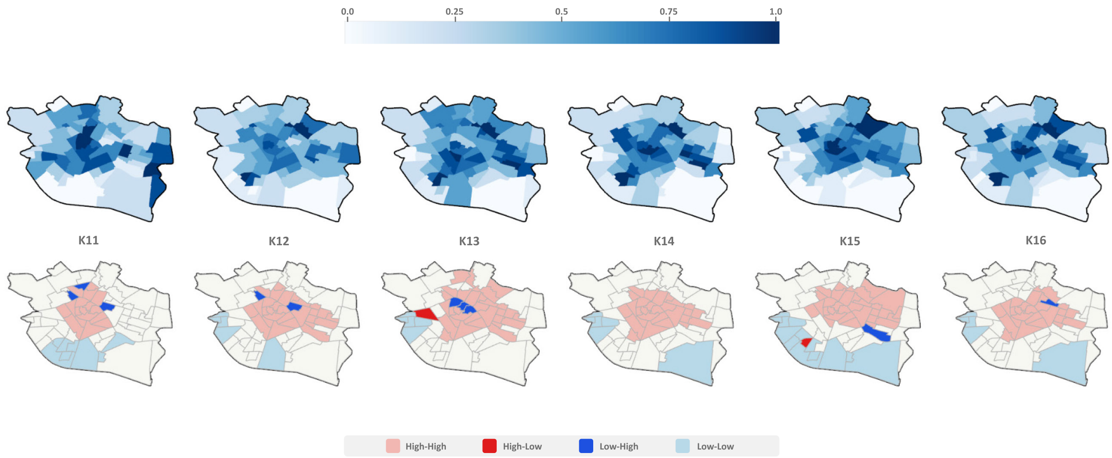

Figure 4. Indicators of the supply (SUP) dimension and its local spatial autocorrelation

Finally, in the leisure and culture dimension (Figure 5), a pattern similar to that observed in the supply dimension is evident, with greater disparities between neighbourhoods compared to the previous dimensions. The three neighbourhoods with the lowest results in this dimension are Natzaret, Sant Isidre, and La Fonteta de Sant Lluís. In contrast, the top three performing neighbourhoods include El Carme, L'Amistat, and La Seu. Notably, indicator K18, which pertains to access to cultural activities, stands out, with nearly 50% of neighbourhoods scoring below 0.5 out of 1.

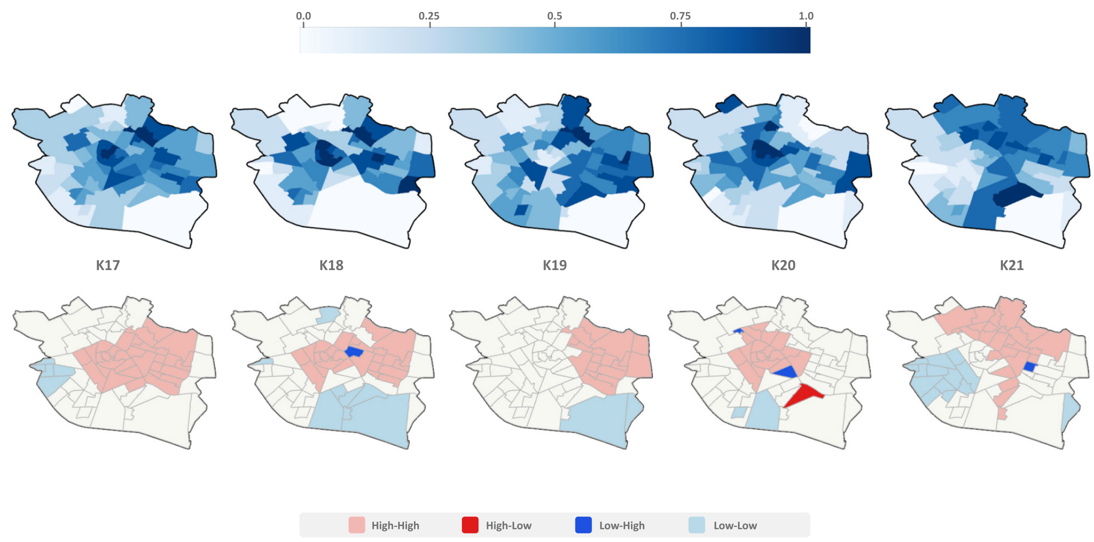

Figure 5. Indicators of the leisure and culture (L&C) dimension and its local spatial autocorrelation

As a general behaviour of the KPIs, values tend to be concentrated in neighbourhoods in the city's central area and its extension towards the northeast. The prevalence of the centre-periphery inequalities described above can be observed in detail in the chloroplastic map of the K12 indicator, which measures the supply of food products (**Figure 6**). A radial decrease in the indicator's value can be seen as the neighbourhoods move away from the city centre. It is also observed that Anselin's *I* statistic classifies those central neighbourhoods that obtain high values in the indicator as HH. In contrast, the neighbourhoods of Malilla, Soternes, La Llum, Fontsanta and Vara de Quart, with low values, are classified in the LL cluster.

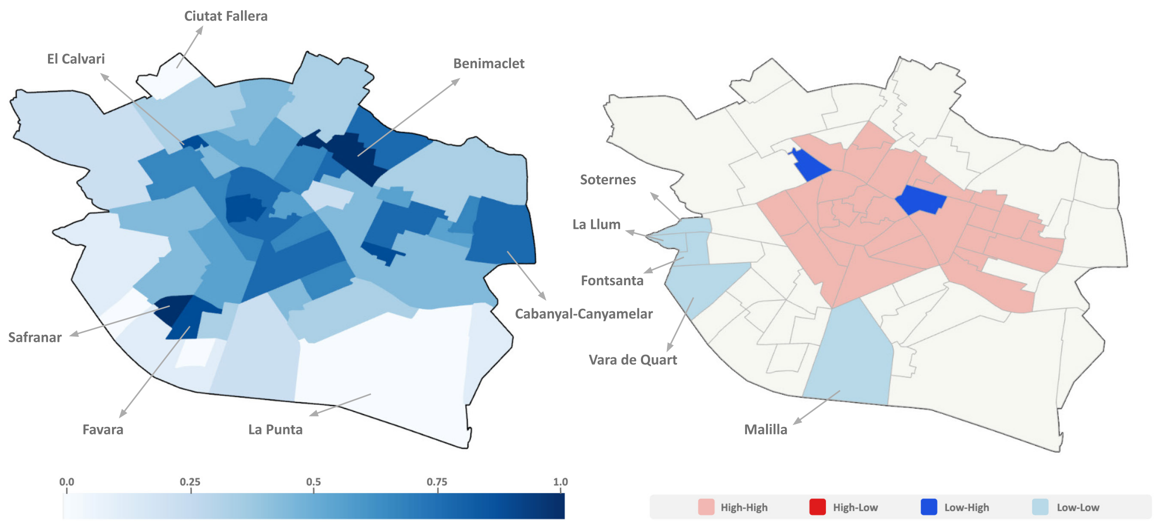

Figure 6. Indicator K12 and its local spatial autocorrelation

DISCUSSION

When analysing the trends observed in neighbourhood values for the calculated KPIs, it has been consistently verified that peripheral areas exhibit significantly lower values across all composite indicators than neighbourhoods in the city's central area and its eastern extension. This pattern reinforces the discourse advocated by urban planners and researchers over the past decades regarding the marginalisation factor in peripheral regions of cities [40].

Since 2020, Valencia has embraced the concept of the 15-minute city and initiated urban planning strategies aimed at positioning the city as a frontrunner in implementing the 15-minute theory, as outlined in its Missions València 2030 program [22]. A key objective of this initiative is to achieve net-zero greenhouse gas (GHG) emissions status by 2030. Despite Valencia's commendable progress towards sustainability goals and its prestigious designation as the European Green Capital for 2024, as well as its favourable standings in the Urban Planning and Social Welfare SDEWES Index [39], there remains an urgent imperative for continued advancements to realise its full potential as a sustainable urban centre.

Achieving greater uniformity in the city's accessibility while ensuring inclusivity of peripheral areas could significantly stride towards decarbonising urban spaces, mitigating the need for a substantial portion of the population to commute extensively. Much of the existing resource scarcity issue stems from the rapid and unregulated expansion experienced by the city during the 1990s and 2000s, exacerbated by real estate speculation. The absence of comprehensive planning and oversight in peripheral neighbourhoods and the marginalisation and social segregation of certain areas likely contributed to the polarisation between the city centre and its outskirts. Moreover, neighbourhoods such as l'Eixample, El Pilar, El Carme, El Mercat, and La Seu have been inhabited by individuals with higher socioeconomic status, as evidenced by the cadastral value of their housing, which is considered an indicator of the residents' purchasing power [41].

Lastly, a special mention should be given to the Benimaclet neighbourhood. Situated in the northeastern part of the city, it exhibits exceptional behaviour compared to other peripheral neighbourhoods with similar socioeconomic attributes. In most of the 21 composite indicators analysed in this study, it ranks among the top 5 neighbourhoods with the most favourable outcomes. Furthermore, when considering the overall average across all indicators, it secures the fifth position, trailing only behind the neighbourhoods of El Pilar, El Carme, El Mercat, and La Seu, which are part of the historic centre of Ciutat Vella in Valencia. The remarkable achievements in this regard can be credited to the robust community self-governance and social mobilisation within the neighbourhood [42], which thrive due to its adjacency to l'Horta de València, the surrounding agricultural lands − a vital source of sustenance, livelihoods, and an integral aspect of the neighbourhood's cultural identity. Aware of the challenges faced by the most underserved areas, such as La Punta, La Llum, Nazaret or Soternes, institutions should reconsider urban planning endeavours and prioritise approaches that emphasise accessibility to resources and foster social cohesion within these communities.

It would be valuable to investigate whether the insights gained from analysing the city's current state can be applied to broader analyses encompassing extended mobility timeframes, aligning with the principles of x-minute cities and diverse transportation modes. Incorporating alternative modes of transportation, such as bicycles or public transit, into the methodology would be of significant interest to institutions. Additionally, the assumption of an average person's movement speed at 4.5 km/h may not accurately represent older age groups or individuals with reduced mobility. Therefore, it is essential to consider these demographic characteristics in the methodology for future research endeavours.

CONCLUSIONS

The study reveals persistent disparities between peripheral and central neighbourhoods in Valencia, with peripheral areas consistently lagging behind in various indicators. Despite strides towards sustainability goals, a pressing need remains to address inequalities and enhance accessibility and inclusivity, particularly in peripheral areas. Historical factors, rapid urban expansion, and social segregation have contributed to this differentiation, highlighting urban planners' complex challenges. However, exceptional cases like the Benimaclet neighbourhood underscore the significance of community involvement and resource access in achieving positive outcomes.

Further urban planning efforts should prioritise improving accessibility and fostering social cohesion in underserved areas. Although the proposed model is adaptable and allows for the incorporation of new data, future research should focus on broader analyses that consider diverse transportation modes and demographic characteristics. Regardless, the proposed model represents a highly valuable tool for institutions that monitor the city's progress, facilitated by the proposed indicators. It holds particular significance in furthering the objectives of the Missions 2030 initiative over the next six years. This concerted effort aims to cultivate more equitable and resilient cities, specifically enhancing mobility and accessibility, thus fostering a more sustainable and inclusive future for all.

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