

Article

Spatial Inequalities in Public Space Quality: A GIS-Based Multi-Attribute Composite Index for Urban Planning in an Intermediate Latin American City

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Abstract

Public spaces are essential for urban well-being, social interaction, environmental quality, and territorial equity; however, their presence does not necessarily ensure adequate quality, accessibility, or multifunctionality. Although previous research has emphasized the importance of green and public spaces, fewer studies have integrated multidimensional quality assessment, GIS-based spatial analysis, and multicriteria prioritization in intermediate Latin American cities. This study aimed to evaluate spatial inequalities in the quality of urban public spaces in Loja, Ecuador, through a GIS-based multi-attribute composite index. A total of 183 public spaces were assessed using structured field observation of observable conditions and organized into six dimensions: functional, environmental, cultural, recreational, safety, and economic. The data were cleaned, validated, integrated with spatial layers, and analyzed through descriptive, inferential, multivariate, spatial autocorrelation, and multicriteria procedures. The results showed that public space quality was mainly concentrated at low and medium levels, with functional and safety dimensions playing a stronger role in the global index, while cultural, recreational, and economic components showed weaker performance. Spatial analysis revealed significant territorial differences, local clusters, and spatial outliers. The proposed framework provides a replicable tool to diagnose observable public space quality, identify priority intervention areas, and support evidence-based urban planning in other intermediate cities.

Keywords: public space quality; spatial inequality; composite index; GIS-based analysis; multicriteria prioritization



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1. Introduction

Public spaces are essential components of urban systems because they support social interaction, mobility, recreation, environmental regulation, and everyday collective life. Their relevance extends beyond physical availability, since their contribution to urban well-being depends on how accessible, safe, comfortable, multifunctional, and socially meaningful they are. Previous studies have shown that public open space attributes are associated with mental health, sense of community, and opportunities for social interaction, demonstrating that qualitative characteristics are as important as spatial provision [1,2]. In this sense, public space quality must be understood as a multidimensional condition that combines physical design, environmental performance, usability, accessibility, and social value. This broader perspective provides the basis for examining how public spaces perform within unequal urban contexts.

Urban green and open spaces are also closely related to sustainability, public health, and environmental justice. Their distribution and quality can influence exposure to environmental benefits, opportunities for physical activity, and access to ecosystem services. However, evidence from urban green space studies shows that availability and accessibility are often uneven across cities, and that spatial indicators are needed to reveal differences in provision, proximity, and effective access [3,4]. These inequalities are particularly relevant because access to public spaces may be conditioned not only by distance, but also by physical barriers, size, attractiveness, usability, and the quality of the surrounding urban environment. Consequently, evaluating public space quality requires integrating spatial and attribute-based dimensions rather than relying only on location or surface area.

The relationship between public space quality and urban well-being becomes especially important in cities undergoing rapid growth, spatial fragmentation, or uneven infrastructure consolidation. Public spaces can contribute to health, social cohesion, ecosystem services, and urban resilience when they are adequately designed, maintained, and connected to everyday urban life [5–7]. Nevertheless, their benefits may be limited when spaces lack accessibility, safety, recreational infrastructure, environmental quality, or opportunities for social and cultural use. This condition creates a gap between the formal existence of public spaces and their real capacity to function as inclusive and active urban environments. For this reason, quality-based evaluations are needed to identify which dimensions condition public space performance and where intervention is most necessary.

In intermediate Latin American cities, the study of public space quality remains less developed than in large metropolitan areas, despite the growing importance of these cities in regional urban systems. These cities often experience territorial expansion, heterogeneous urban consolidation, limited municipal resources, and differences in infrastructure provision among neighborhoods or parishes. Research on urban green-space planning has emphasized that cities facing densification or uneven growth require strategies that preserve, improve, and equitably distribute high-quality open spaces [8]. At the same time, studies on green justice and human well-being show that the benefits of green and public spaces depend on both their distribution and their capacity to respond to social needs [9,10]. This situation creates a methodological and practical need for tools capable of diagnosing public space quality with spatial precision in intermediate urban contexts.

A key research gap concerns the integration of multidimensional quality assessment, spatial analysis, and decision-support methods within a single framework for urban public space planning. Previous studies have examined green equity, accessibility, public space perception, or spatial distribution, but many approaches focus on one dimension of the problem rather than combining physical quality, territorial inequality, and intervention prioritization. Spatial equity research has shown that access to urban vegetation and public amenities may differ significantly among territories and population groups, reinforcing the need for geographically explicit assessments [11]. Similarly, GIS-based network and accessibility approaches demonstrate the value of spatial methods for identifying unequal service conditions across urban areas [12,13]. These contributions support the need to develop integrated frameworks that can be applied to intermediate cities and adapted to local planning requirements.

This study aims to evaluate spatial inequalities in the quality of urban public spaces in Loja, Ecuador, through a GIS-based multi-attribute composite index. To achieve this objective, structured field observation data were collected for urban public spaces and organized into functional, environmental, cultural, recreational, safety, and economic dimensions. The information was cleaned, standardized, and integrated with spatial data to construct a composite index and analyze territorial patterns. Descriptive, inferential, multivariate, spatial autocorrelation, and multicriteria procedures were applied to assess

the behavior of the index and identify priority intervention areas. This methodological design is aligned with previous approaches that emphasize the need to monitor accessible and attractive urban green spaces, understand the spatial logic of parks, and use location-based models to support planning decisions [14–16].

The scope of this study is limited to the evaluated urban public spaces of Loja and to the dimensions measured through the field instrument, but the proposed framework offers broader technical and scientific contributions. First, it provides a replicable procedure for transforming structured observation data into a composite public space quality index. Second, it links the resulting index with GIS-based spatial analysis, enabling the identification of territorial inequalities, local clusters, and spatial outliers. Third, it incorporates multicriteria prioritization as a decision-support component for urban planning, recognizing that public space interventions must consider several criteria simultaneously. In this sense, the study contributes to evidence-based public space planning by connecting quality, equity, accessibility, restorative value, and perceived access as key dimensions for diagnosing and prioritizing urban interventions [17–20].

This study therefore focuses on the observable quality conditions of public spaces rather than on user perception. This scope allows the proposed framework to generate a standardized and spatially comparable diagnosis, while recognizing that future studies may complement the results with perception-based, socioeconomic, or participatory information.

2. Materials and Methods

2.1. Methodological Design of the Study

The study was developed under a quantitative, spatial, and multicriteria approach aimed at evaluating the quality of urban public spaces in the city of Loja, Ecuador. The unit of analysis corresponded to each public space identified within the urban parishes considered in the survey: Carigán, Sucre, Punzara, El Valle, El Sagrario, and San Sebastián.

The methodology was structured into five articulated phases. First, primary information was collected through structured field observation. Second, an analytical database was constructed through data cleaning, standardization, and record validation. Third, a composite public space quality index was formulated, based on functional, environmental, cultural, recreational, safety, and economic dimensions. Fourth, descriptive, inferential, and multivariate statistical analyses were applied to characterize the behavior of the index and its dimensions. Finally, spatial and multicriteria analyses were conducted to represent territorial patterns, identify local spatial associations, and prioritize spaces with greater relative intervention needs.

This design made it possible to integrate observational information, spatial attributes, and quantitative evaluation procedures into a common methodological structure. The adoption of a multidimensional approach responds to the complex nature of public space, whose quality cannot be assessed solely through a single variable, but rather through the integration of physical, functional, environmental, social, and use-related conditions [21,22].

2.2. Sample Description and Unit of Analysis

The sample consisted of urban public spaces previously identified within the urban area of Loja. Each space was considered an independent unit of analysis and received a unique code before the information collection process. This coding system made it possible to maintain traceability between the field record, the tabular database, the spatial layer, and the subsequent analyses.

The code assigned to each space incorporated information on both typology and urban parish. The alphabetic prefix allowed the spaces to be classified as urban park, district

park, square, neighborhood park, or communal green area. The intermediate numerical component of the code allowed the corresponding urban parish to be identified. This coding structure made it possible to standardize the sample, reduce identification errors, and ensure correspondence between the collected records and the spatial geometries used in the cartographic analysis.

The information collection process was carried out in two periods, corresponding to the years 2023 and 2024. The final database was built from valid records associated with structured public space codes, excluding empty observations, summary records, or entries with no correspondence to the defined coding structure.

The geographical location of the study area is shown in Figure 1. The main map displays the urban reference boundary of Loja, the final parish reference zones used for cartographic visualization, and the evaluated public spaces included in the analysis. The inset map locates Loja within mainland Ecuador.

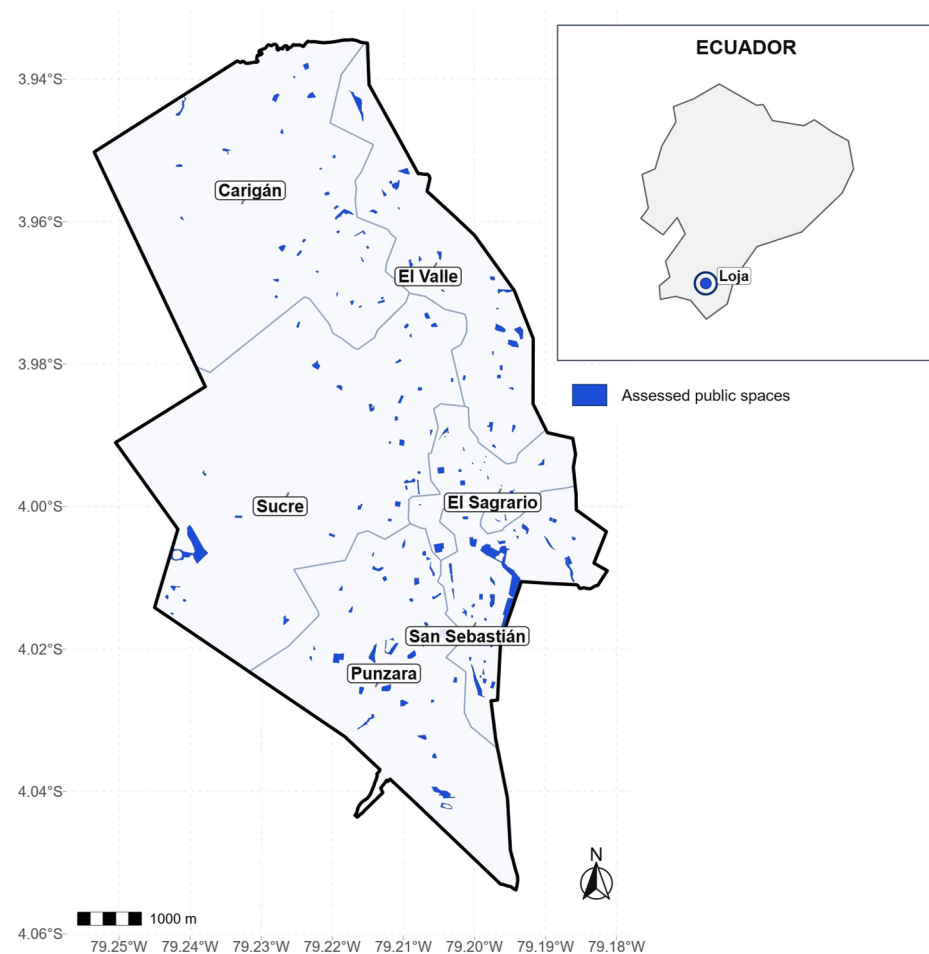


Figure 1. Study area and evaluated public spaces in Loja, Ecuador.

According to the 2022 Population and Housing Census, the urban area of Loja had 203,496 inhabitants. The evaluated public spaces were distributed across the six urban parishes of the city: Carigán, Sucre, Punzara, El Valle, El Sagrario, and San Sebastián. Their territorial distribution was characterized using the number and typology of evaluated spaces, the assessed surface area, and the reference population associated with each public space.

As shown in Table 1, the study included 183 public spaces, comprising 127 neighborhood parks, 35 communal green areas, 17 squares, three district parks, and one urban park. The evaluated spaces covered a total surface area of 97.20 ha and were associated with a

reference population of 64,926 inhabitants. San Sebastián contained the largest number of evaluated spaces and the greatest assessed surface area, with 34 spaces covering 28.77 ha, followed by Punzara and Sucre, each with approximately 20.3 ha. El Sagrario had the smallest assessed surface area, with 5.13 ha.

Table 1. Territorial context of the evaluated public spaces by urban parish.

Urban Parish	Neighborhood Parks (n)	Communal Green Areas (n)	Squares (n)	District Parks (n)	Urban Parks (n)	Total Public Spaces (n)	Assessed Area (ha)	Reference Population
Carigán	21	8	0	0	0	29	8.80	7200
Sucre	24	7	2	0	0	33	20.25	14,086
Punzara	23	7	1	1	0	32	20.35	14,085
El Valle	22	7	1	0	0	30	13.91	6268
El Sagrario	14	1	10	0	0	25	5.13	5908
San Sebastián	23	5	3	2	1	34	28.77	17,379
Total	127	35	17	3	1	183	97.20	64,926

Note. The reference population corresponds to the population associated with each evaluated public space in the project database. Because the areas of influence of different public spaces may overlap, parish-level and total values should not be interpreted as counts of unique inhabitants served. The urban population of Loja was 203,496 inhabitants according to the 2022 Population and Housing Census.

The reference population corresponds to the population assigned to each public space in the project database and was used to characterize the territorial coverage of the sample. It should not be interpreted as the number of unique inhabitants served or as a direct proportion of Loja's total urban population, since the areas of influence of different public spaces may overlap. This territorial characterization provides the spatial and demographic context for interpreting parish-level variations in public space quality.

2.3. Field Data Collection

Primary information was collected through fieldwork with the support of architecture students from the Universidad Técnica Particular de Loja, who were previously assigned to the coded public spaces. Data collection was carried out using KoboToolbox, a digital platform that enables the design of forms, the collection of information through mobile devices, database management, and monitoring or field research processes [23].

The use of a digital tool made it possible to structure the form with mandatory fields, closed response lists, dichotomous questions, ordinal questions, and photographic records. This strategy contributed to reducing transcription errors, improving data traceability, and visually supporting the information collected in the field. Each student was assigned a set of previously coded public spaces, and the form required the registration of the surveyor's name, date and time of the survey, parish, public space code, and photographs of the evaluated area.

Data collection was based on direct observation of physical, functional, and use-related attributes of public space. This procedure made it possible to construct a comparable database across spatial units by applying the same instrument to all evaluated spaces.

2.4. Public Space Quality Assessment Instrument

The data collection instrument was designed as a structured observation sheet to assess the quality of public spaces across six dimensions: functional, environmental, cultural expression, recreation, safety, and economic. The selection of these dimensions was based on public space assessment approaches that recognize the need to measure observable attributes related to accessibility, functionality, safety, maintenance, comfort, services, activities, and contextual conditions of the urban environment [24–26]. In addition, the instrument was informed by Latin American academic and technical frameworks on public space quality, environmental quality, and public space habitability, which organize

public space assessment around functional, environmental, cultural, recreational, safety, infrastructure, service, and economic-use dimensions [27–29]. Rather than reproducing a single pre-existing instrument, the assessment framework was constructed as a contextual adaptation of these sources to the urban public spaces of Loja. The final set of variables was selected according to three methodological criteria: field observability, relevance to the typologies of public spaces evaluated in the study, and comparability across spatial units.

The functional dimension assessed conditions of permanence, accessibility, and connectivity. It included questions on the presence of benches, walking time to access public transport, the existence of ramps, tactile paving surfaces, and physical barriers that hinder internal mobility. This dimension made it possible to approximate the capacity of the space to facilitate access, permanence, and user mobility. This dimension operationalized the broader concepts of mobility, accessibility, functionality, and infrastructure identified in previous public space indicator frameworks.

The environmental dimension recorded attributes associated with tree cover and maintenance of green areas. The instrument required counting large, medium, and small trees, defined according to approximate crown diameter, as well as classifying the maintenance of green areas as good, regular, or poor. This dimension made it possible to incorporate visible environmental quality elements within the public space. This dimension was aligned with environmental sustainability and physical-natural components commonly used to evaluate public space quality and habitability.

The cultural expression dimension assessed the presence or possibility of artistic and cultural activities. It included questions on the presence of artists, the occurrence of artistic expression events, the existence of suitable areas for artistic expression, the occurrence of cultural events or festivities, and the availability of spaces that could serve cultural activities. This dimension made it possible to consider the capacity of the space to host community, artistic, or festive expressions. This dimension was included because public spaces are also evaluated by their capacity to support symbolic, cultural, social, and community practices.

The recreational dimension assessed the existence of infrastructure for active or passive recreation through questions on the presence of playgrounds and recreational furniture. The safety dimension considered surveillance, control, and lighting attributes, including the presence of security personnel, surveillance cameras, lighting on adjacent streets, and lighting inside the public space. Finally, the economic dimension recorded the presence of permanent or informal commercial activities through questions on kiosks and street vending. These three dimensions were incorporated to capture key aspects of public space use, including leisure opportunities, observable safety conditions, and everyday economic activity.

The instrument combined dichotomous, ordinal, and count variables. Dichotomous variables recorded the presence or absence of attributes; ordinal variables made it possible to assess conditions such as maintenance; and count variables allowed observable elements, such as trees by category, to be quantified. This structure made it possible to transform qualitative and observational information into comparable scores across spaces. Accordingly, the instrument should be understood as an observational quality audit focused on physical, functional, environmental, and use-related attributes of public spaces; it was not intended to replace user perception surveys, but to provide a standardized and spatially comparable diagnosis of observable public space conditions.

2.5. Construction of the Composite Public Space Quality Index

Based on the field instrument, a composite public space quality index was constructed to synthesize the joint behavior of several observable dimensions into a single measure. Composite indicators are useful when it is necessary to represent multidimensional phe-

nomena through an integrated metric, especially in urban evaluation processes involving physical, functional, environmental, social, and use-related criteria. Their construction involves defining dimensions, indicators, measurement scales, weights, and an aggregation procedure that allows units of analysis to be compared under a common structure [30]. In this study, the index was developed as a context-specific composite indicator derived from the convergence between previous public space quality frameworks, Latin American habitability indicators, technical indicator systems, and the empirical conditions observed in the public spaces of Loja [27–29]. This approach is consistent with previous public space evaluation studies that have used multidimensional indices or instruments to assess attributes such as accessibility, safety, comfort, meaning, functionality, activities, environmental conditions, and physical quality of the surroundings [24,25]. Table 2 presents the conceptual traceability of the index dimensions and shows how the components identified in previous frameworks were operationally adapted to the variables included in the field instrument.

Table 2. Conceptual traceability of the composite public space quality index.

Index Dimension	Conceptual Basis in Previous Frameworks	Operational Adaptation in This Study
Functional	Mobility, accessibility, infrastructure, permanence, and internal usability	Benches, walking time to public transport, ramps, tactile paving surfaces, and physical barriers
Environmental	Environmental sustainability, physical-natural conditions, green areas, and environmental comfort	Tree cover by size and maintenance condition of green areas
Cultural	Cultural dynamics, symbolic expression, identity, and community activities	Presence of artists, artistic events, cultural events, and spaces suitable for cultural activities
Recreation	Leisure, recreation, play, and active/passive use of public space	Playgrounds and recreational furniture
Safety	Safety and protection, lighting, surveillance, and control	Security personnel, surveillance cameras, lighting on adjacent streets, and lighting inside the public space
Economic	Economy and consumption, commercial activity, and everyday use dynamics	Kiosks and street vending

Note. The table summarizes the methodological correspondence between the conceptual dimensions identified in previous public space quality and habitability frameworks and the variables operationalized in the field instrument. The index was therefore constructed as a contextual adaptation rather than as a direct replication of a single external scoring system.

This conceptual correspondence provided the basis for organizing the observed variables into six dimensions and for subsequently defining their coding, normalization, weighting, and aggregation within the composite index.

The index was structured around six analytical dimensions: functional, environmental, cultural, recreation, safety, and economic. Each dimension was transformed into a partial quality score according to a previously defined maximum scale. The functional dimension was valued over a maximum of 30 points; the environmental and safety dimensions over 20 points each; and the cultural, recreation, and economic dimensions over 10 points each. This structure is equivalent to a percentage weighting of 30%, 20%, 10%, 10%, 20%, and 10%, respectively. The assignment of these weights responded to a normative-methodological criterion, in which greater relevance was given to the components directly associated with accessibility, internal mobility, permanence, environmental comfort, and safety conditions of public space, while maintaining complementary dimensions linked to

cultural expression, recreation, and economic activity. This weighting structure was defined as an explicit analytical decision grounded in the conceptual relevance of each dimension for the physical usability, environmental performance, and everyday functioning of public spaces. It was not derived from expert elicitation methods such as Delphi or AHP; therefore, alternative weighting scenarios and multicriteria procedures were later applied to assess the stability of the prioritization outputs.

The global public space quality index was calculated through a weighted sum of the normalized scores of each dimension. To do so, each partial score was divided by its theoretical maximum value and then multiplied by its relative weight within the index. The general formulation was as follows:

$$PSQI_i = 100 \times \left[0.30 \left(\frac{F_i}{30} \right) + 0.20 \left(\frac{A_i}{20} \right) + 0.10 \left(\frac{C_i}{10} \right) + 0.10 \left(\frac{R_i}{10} \right) + 0.20 \left(\frac{S_i}{20} \right) + 0.10 \left(\frac{E_i}{10} \right) \right]$$

where $PSQI_i$ represents the Public Space Quality Index for public space i ; F_i corresponds to the functional dimension score; A_i , to the environmental dimension score; C_i , to the cultural dimension score; R_i , to the recreation dimension score; S_i , to the safety dimension score; and E_i , to the economic dimension score. The denominators 30, 20, 10, 10, 20, and 10 represent the maximum values assigned to each dimension, whereas the coefficients 0.30, 0.20, 0.10, 0.10, 0.20, and 0.10 represent their relative weights in the overall index.

Since the maximum scores of the dimensions sum to 100 points, the previous expression is equivalent to the direct sum of the partial scores, provided that each dimension has been previously constructed on the established maximum scale:

$$PSQI_i = F_i + A_i + C_i + R_i + S_i + E_i$$

This equivalence made it possible to calculate the global index directly while preserving the percentage contribution of each dimension to the total index. To verify the consistency of the calculation, the recorded global value was compared with the sum of the partial dimension scores. Records with an absolute difference of less than 0.0001 were considered consistent. The additive aggregation assumes partial compensation among dimensions; therefore, a high score in one dimension may offset a lower score in another. To avoid interpreting the global index as the sole diagnostic output, each dimension was also analyzed separately, and multicriteria and sensitivity analyses were incorporated as complementary verification procedures.

To facilitate the interpretation of the global index, the scores were classified into five quality levels: very low, low, medium, high, and very high. The classification was carried out using regular 20-point intervals, considering the theoretical range from 0 to 100. Thus, values below 20 points were classified as very low quality; values from 20 to less than 40 as low; values from 40 to less than 60 as medium; values from 60 to less than 80 as high; and values equal to or greater than 80 as very high quality. This categorization made it possible to transform the continuous index score into ordinal interpretation levels, facilitating comparison among public spaces and communication of results for diagnostic, prioritization, and urban intervention purposes. Because these thresholds are analytical classification intervals rather than externally validated quality standards, the continuous index values and the dimensional scores were retained throughout the analysis to avoid relying exclusively on categorical interpretation.

2.6. Data Cleaning, Depuration, and Treatment

Data depuration was conceived as a methodological phase aimed at ensuring integrity, consistency, and comparability among records. The database was constructed from the 2023 and 2024 information surveys. Only records with valid codes were retained, defined by

an alphanumeric structure such as VC-1-008, BA-5-012, or other equivalent combinations. This rule made it possible to ensure that each observation corresponded to a coded and traceable public space.

Numerical variables were standardized by converting decimal commas into decimal points and subsequently transforming them into numeric format. Parish and typology variables were reconstructed from the public space code. For the parish, the intermediate number in the code was used; for typology, the alphabetic prefix was used. Codes with the prefix PU were classified as urban park, PD as district park, PL as square, and VC as communal green area. Two prefixes, PB and BA, were retained for neighborhood parks because they came from the original field and spatial coding system. Both prefixes referred to neighborhood-scale parks and did not represent different analytical typologies. Therefore, they were harmonized into a single analytical category, neighborhood park, while preserving the original codes to maintain traceability between the field records, the tabular database, and the spatial layer. This harmonization did not imply duplicate records or double counting, but only the consolidation of two operational prefixes into one analytical typology.

The treatment included verification of duplicates, validation of theoretical ranges, and consistency checking of the global index. Zero values were retained as valid data because they represented the absence of the observed attribute or null performance in certain components of the instrument, rather than errors or missing values. This criterion was applied uniformly in the descriptive, inferential, spatial, and multicriteria analyses. This decision was particularly relevant for dimensions measured through presence/absence indicators, such as cultural expression, recreation, and economic activity. In these cases, zero values reflected an empirical condition of the evaluated public space, such as the absence of a facility, activity, or observable attribute, and were therefore preserved as substantive information rather than treated as missing data.

2.7. Statistical Analysis Strategy

The statistical analysis was designed to characterize the structure of the index, evaluate differences among territorial and typological groups, and explore relationships among dimensions. Processing was performed in R version 4.5.3 (11 March 2026 ucrt), using RStudio version 2026.1.1.403 as the integrated development environment. R was used as a language for data analysis, statistical computing, and graphical representation, supporting the reproducibility of the analytical workflow [31].

The statistical processing used the packages readxl version 1.4.5, writexl version 1.5.4, stringr version 1.6.0, openxlsx version 4.2.8.1, ggplot2 version 4.0.2, svglite version 2.2.2, ranger version 0.18.0, scales version 1.4.0, and ggrepel version 0.9.7. The packages readxl, writexl, and openxlsx were used for reading and exporting tabular files; stringr for reconstructing alphanumeric patterns; ggplot2, scales, svglite, and ggrepel for visualization; and ranger for complementary variable importance analysis using Random Forest.

The descriptive characterization included diagnosis of missing data and zero values, as well as the calculation of minimum, first quartile, mean, median, third quartile, maximum, standard deviation, coefficient of variation, and interquartile range. These statistics made it possible to describe the distribution of the global index and its dimensions without assuming normality of the data.

The association among dimensions was evaluated using Pearson, Spearman, and Kendall correlation matrices. Spearman's correlation was prioritized for the main presentation because of its usefulness in identifying monotonic associations and its lower dependence on normality assumptions. The normality of the variables was assessed using the Shapiro–Wilk test. To test differences in the global index among parishes and typologies,

the Kruskal–Wallis test was applied, complemented with post hoc pairwise Wilcoxon tests with Bonferroni adjustment.

Additionally, principal component analysis was performed based on the six dimensions of the index. Before its application, only complete cases and variables with positive variance were retained. The analysis was conducted with centering and scaling of variables, with the purpose of synthesizing the joint variability of the dimensions into comparable orthogonal components. Components with eigenvalues greater than 1 were considered the main components for interpretation.

A Random Forest model was also incorporated to assess the relative importance of the dimensions in the structure of the global index. This analysis was used for diagnostic and complementary purposes, considering that the global index was constructed as the sum of the partial dimensions. Finally, multicriteria prioritization procedures, sensitivity analysis, and critical dimension classification were applied to support the identification of spaces with greater relative intervention needs.

2.8. Spatial Analysis Strategy

The spatial analysis made it possible to link quality scores with the geographic location of public spaces. This phase was based on the integration of the depurated analytical database with a vector layer of public spaces. Spatial data handling was performed using the *sf* package, which implements the Simple Features standard for reading, writing, manipulating, and analyzing vector data in R [32].

When the geometries contained Z or M dimensions, these were removed to retain two-dimensional geometries compatible with cartographic analysis. Subsequently, the geometries were validated and transformed to the EPSG:32717 coordinate reference system, corresponding to WGS 84/UTM zone 17S. The join between the tabular database and the spatial layer was performed using the unique public space code.

From the spatial integration, geometric areas were calculated in square meters and hectares, as well as derived variables for classification, deficit, and spatial prioritization. The spatial analysis was maintained in EPSG:32717 to preserve metric coherence, while visualization with a cartographic background was performed in EPSG:3857 due to its compatibility with Web Mercator base layers.

2.9. Global and Local Spatial Autocorrelation

Spatial autocorrelation was used to evaluate whether the values of the global index exhibited spatial dependence. For this purpose, the global Moran's I index and Local Indicators of Spatial Association (LISA) were employed. LISA decomposes global autocorrelation into local contributions, identifying spatial concentrations of high values, concentrations of low values, and spatial outliers [33].

The analysis was implemented using the *spdep* package version 1.4.2, which was used to construct neighborhood relationships, spatial weights matrices, and spatial autocorrelation tests. The use of this package was supported by previous methodological work comparing implementations of global and local indicators of spatial association, including Moran's I and local indicators [34]. To construct the neighborhood structure, representative points of the public space polygons were used, and a nearest-neighbor matrix was defined using *k*-nearest neighbors. The number of neighbors was set to six, conditioned by the available size of the spatial sample. A *k*-nearest-neighbor structure was selected because the evaluated public spaces are distributed as irregular and non-contiguous polygons; therefore, a contiguity-based matrix could produce isolated observations or unstable neighborhood definitions. The use of ($k = 6$) ensured that each observation had the same number of spatial neighbors and allowed local spatial association to be evaluated under a

homogeneous neighborhood structure. This specification was treated as a methodological decision and, given its potential influence on LISA results, its implications are considered in the study limitations.

Based on this structure, a row-standardized spatial weights matrix was generated. Subsequently, global Moran's I was calculated for the global index, and local Moran indicators were estimated to classify observations into High-High, Low-Low, High-Low, Low-High, and non-significant clusters.

2.10. Spatial Prioritization and Multicriteria Analysis

Spatial prioritization was proposed as a phase to support urban decision-making. First, a global deficit indicator was constructed, defined as the difference between the theoretical maximum value of the index and the observed score for each public space. This indicator made it possible to rank spaces according to their relative intervention need.

As a complement, Multiple Attribute Decision-Making (MADM) procedures were applied to evaluate the stability of the prioritization under different methods and weighting scenarios. Multicriteria methods are relevant in urban problems because they allow alternatives to be compared while simultaneously considering multiple criteria, dimensions, or constraints [35]. In this study, the MADM procedures were not used to replace the composite index, but to examine whether the identification of priority spaces remained consistent when alternative aggregation logics and weighting assumptions were applied.

The methods considered were WSM, TOPSIS, and VIKOR. TOPSIS ranks alternatives according to their proximity to a positive ideal solution and their distance from a negative ideal solution; VIKOR is based on a compromise solution logic for multicriteria problems with potentially conflicting criteria; and WSM allows direct weighted aggregation of criteria. The joint use of these methods made it possible to assess whether the spaces with the greatest deficits maintained critical positions under different multicriteria aggregation schemes [36].

The weighting scenarios included original weights, equal weights, human-centered orientation, environmental orientation, entropy-derived weights, and CRITIC weights. The CRITIC method allows objective weights to be obtained from the variability of criteria and the contrast of information derived from intercriteria correlations [37]. The use of several scenarios made it possible to evaluate the relative consistency of the rankings and reduce dependence on a single weighting scheme. This step was incorporated to address the normative nature of the original weights and to provide a robustness check for the prioritization outputs.

Additionally, a sensitivity analysis was applied through Monte Carlo simulations, aimed at evaluating the stability of the relative position of public spaces under variations in the weights assigned to the dimensions. This procedure made it possible to complement the main prioritization and verify the robustness of the multicriteria ranking.

3. Results

3.1. Consolidation of the Analytical Database and Index Consistency

The analytical database consisted of 183 urban public spaces evaluated in the city of Loja. Of the total number of records, 96 corresponded to the 2023 survey and 87 to the 2024 survey. The construction of the database involved record cleaning, variable standardization, the reconstruction of parish and typology based on the identification code, and the validation of the global index as the sum of six dimensions: functional, environmental, cultural, recreational, safety, and economic.

As shown in Table 3, no duplicate codes were identified in the final analytical database. Likewise, all records remained within the expected theoretical ranges. The internal valida-

tion confirmed that the global index corresponds to the sum of the functional, environmental, cultural, recreational, safety, and economic dimensions, which allowed the database to be used as input for the subsequent descriptive, inferential, and spatial analyses.

Table 3. Analytical database diagnosis and validation of the global index.

Indicator	Value
Records corresponding to 2023	96
Records corresponding to 2024	87
Consolidated records	183
Records included in the analytical database	183
Duplicate codes identified	0
Global minimum value	12.00
Global mean value	38.00
Global median value	38.00
Global maximum value	77.75
Global standard deviation	15.58
Records with correct global validation	183
Records requiring global validation review	0
Records with correct ranges	183
Records requiring range review	0

Note. This table summarizes the consolidation, cleaning, and validation process of the database used for the analysis. No duplicate codes or inconsistencies were identified in the global validation or range-checking procedures.

3.2. General Behavior of the Global Index and Its Dimensions

As shown in Table 4, the global index presented a mean and median of 38.00 points, with values ranging from 12.00 to 77.75. These values indicate that the evaluated public spaces were mainly concentrated in the lower half of the theoretical 0–100 scale. Among the dimensions, safety recorded the highest mean value, followed by functional and environmental. In contrast, recreational, cultural, and economic dimensions showed the weakest performance, indicating limited recreational infrastructure, cultural-use conditions, and economic activity in many evaluated spaces.

Table 4. Descriptive statistics of the quality dimensions and the global public space index.

Variable	<i>n</i>	Missing	Zero Values	Zero Values (%)	Min	Q1	Mean	Median	Q3	Max	SD	CV	IQR
Functional	183	0	3	1.64	0.00	3.00	9.81	9.50	16.00	27.50	7.38	0.75	13.00
Environmental	183	0	0	0.00	3.50	7.50	9.16	9.50	11.00	15.50	2.69	0.29	3.50
Cultural	183	0	68	37.16	0.00	0.00	3.13	4.00	6.00	10.00	2.98	0.95	6.00
Recreational	183	0	93	50.82	0.00	0.00	3.22	0.00	6.63	10.00	3.67	1.14	6.63
Safety	183	0	0	0.00	1.75	6.88	11.10	9.00	15.75	20.00	4.80	0.43	8.88
Economic	183	0	133	72.68	0.00	0.00	1.58	0.00	5.00	10.00	2.76	1.74	5.00
Global	183	0	0	0.00	12.00	25.13	38.00	38.00	48.88	77.75	15.58	0.41	23.75

Note. *n* = number of observations; SD = standard deviation; CV = coefficient of variation; IQR = interquartile range; Q1 = first quartile; Q3 = third quartile. Values were rounded to two decimal places for presentation.

The distribution of the global index is presented in Figure 2. The histogram shows that most values are located below 60 points, consistent with the predominance of low and medium quality levels. Figure 3 complements this result by showing the dispersion of the evaluated dimensions. The main pattern emerging from the boxplots is the contrast between dimensions with broader performance ranges, such as functional and safety, and dimensions with a high concentration of low or zero values, particularly economic, recreational, and cultural.

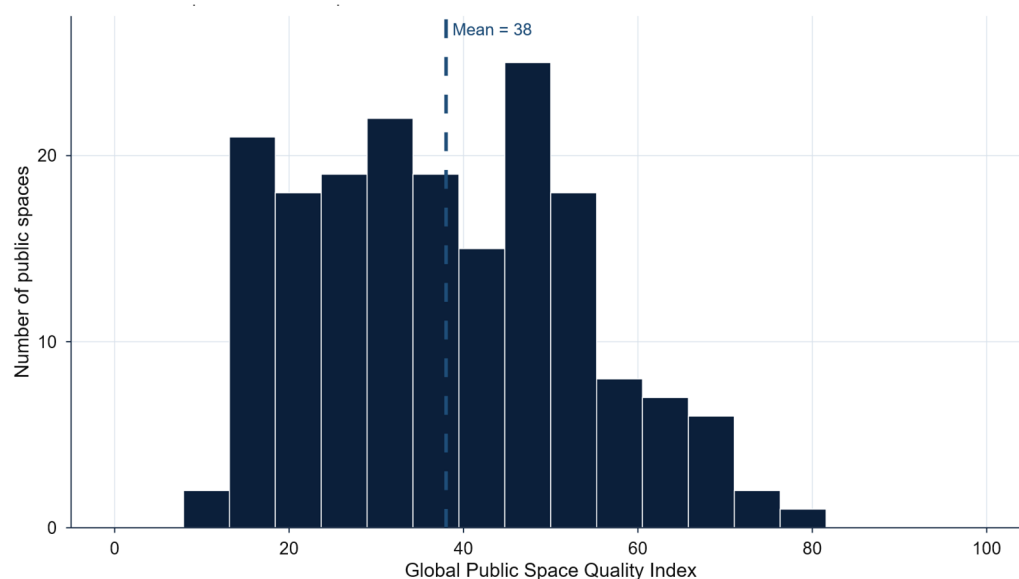


Figure 2. Distribution of the global public space quality index.

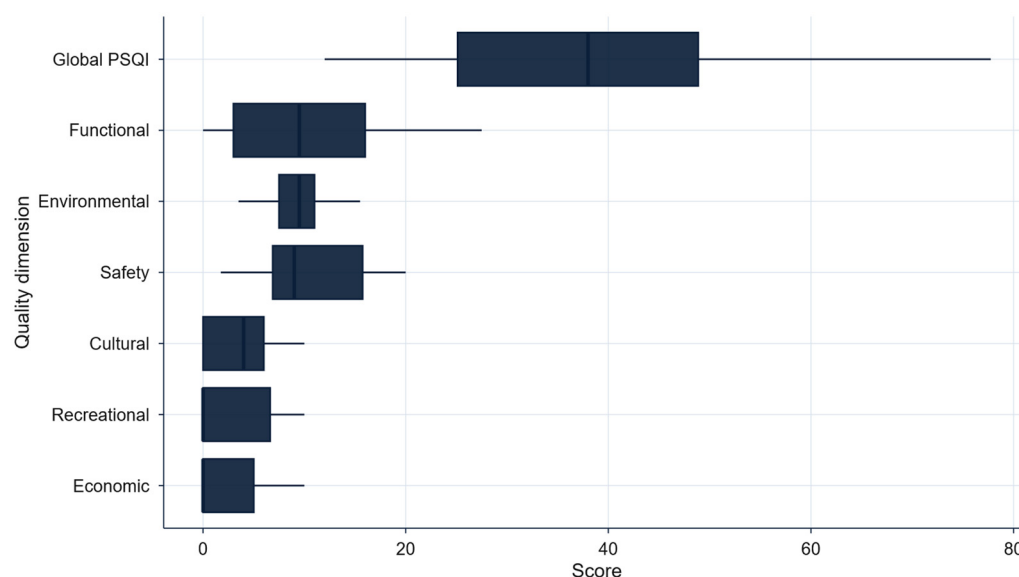


Figure 3. Distribution of the dimension scores and the global index.

As shown in Table 5, the largest proportion of spaces was classified within the low and medium levels. Most evaluated spaces did not exceed the medium-quality threshold, and none reached the very high-quality category. This confirms that the presence of public spaces in the urban area does not necessarily imply consolidated multidimensional quality.

Table 5. Classification of public spaces by global quality level.

Global Quality Level	<i>n</i>	Percentage (%)
Very low	27	14.75
Low	74	40.44
Medium	66	36.07
High	16	8.74
Very high	0	0.00
Total	183	100.00

Note. Percentages were calculated based on the total number of observations ($n = 183$) and rounded to two decimal places for presentation.

3.3. Territorial Distribution and Differences by Urban Parish

Figure 4 shows the territorial distribution of the evaluated public spaces by urban parish within the urban area of Loja.

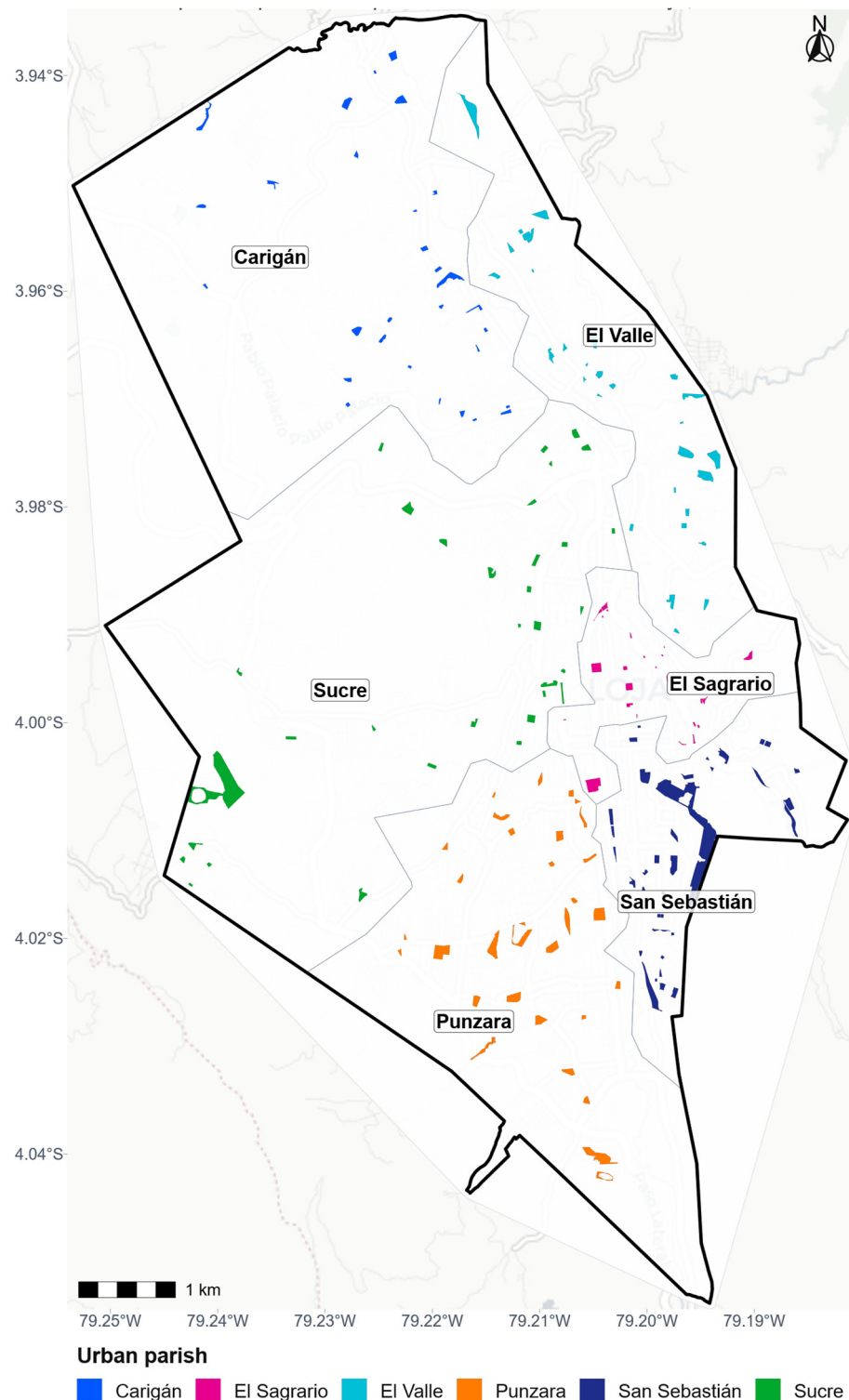


Figure 4. Territorial distribution of evaluated public spaces by urban parish in Loja, Ecuador.

The sample presented a relatively balanced territorial distribution among the six urban parishes analyzed. San Sebastián concentrated 34 evaluated spaces, Sucre 33, Punzara 32, El Valle 30, Carigán 29, and El Sagrario 25. By typology, neighborhood parks predominated, with 127 spaces, followed by communal green areas, with 35 spaces; squares, with 17 spaces;

district parks, with 3 spaces; and urban parks, with 1 space. This distribution allows territorial comparison among the evaluated public spaces, although the results should be interpreted as differences in the assessed spaces and not as causal explanations based on parish-level socioeconomic conditions.

According to Table 6, San Sebastián, El Sagrario, and Punzara recorded the highest mean global scores, whereas Sucre and Carigán showed the lowest mean values. The main territorial finding is not only the difference between parish means, but also the unequal concentration of spaces below the overall mean. In Carigán and Sucre, most evaluated spaces were below the global mean, suggesting weaker local performance of public space quality in these areas. El Valle occupied an intermediate position, with more than half of its evaluated spaces below the mean.

Table 6. Global quality index by urban parish.

Parish	<i>n</i>	Mean Global Score	Median Global Score	Min	Max	SD	CV	Below Mean	Above or Equal to Mean	Below Mean (%)
San Sebastián	34	43.59	45.88	12.00	77.75	16.85	0.39	11	23	32.35
El Sagrario	25	42.87	40.00	15.50	70.00	16.35	0.38	11	14	44.00
Punzara	32	41.36	41.63	16.50	65.50	12.51	0.30	12	20	37.50
El Valle	30	37.03	34.25	14.50	68.00	13.95	0.38	17	13	56.67
Sucre	33	32.82	32.75	16.75	55.00	12.03	0.37	21	12	63.64
Carigán	29	30.46	27.00	12.25	71.00	17.62	0.58	21	8	72.41

Note. *n* = number of observations; SD = standard deviation; CV = coefficient of variation. Percentages and descriptive statistics were rounded to two decimal places for presentation.

Figure 5 shows the internal variability of public spaces within each parish and complements Table 6 by representing the dispersion of values within each territorial unit.

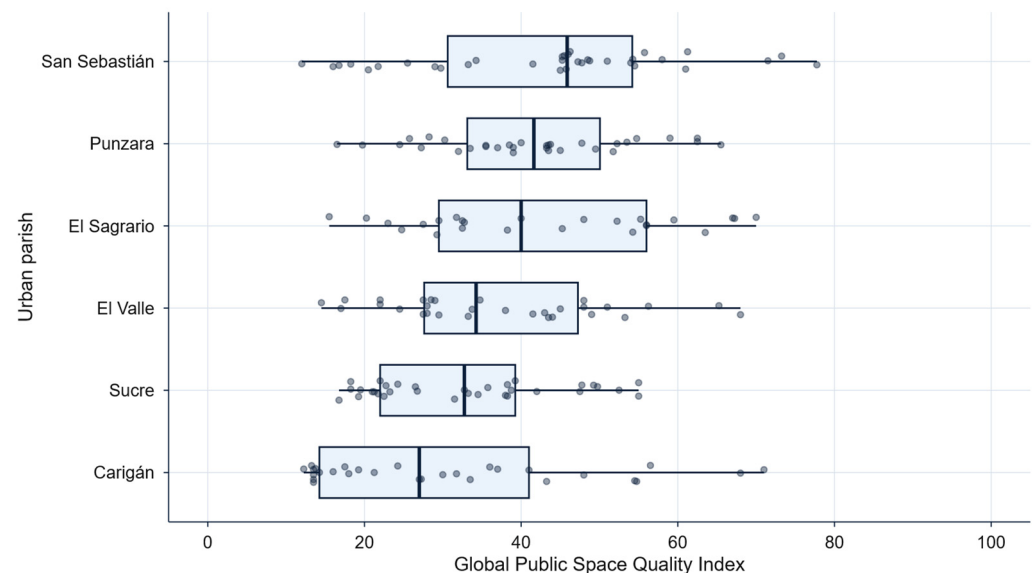


Figure 5. Distribution of the global index by urban parish.

The spatial distribution of the global index is presented in Figure 6. This figure shows the location of spaces with different index values and allows the descriptive results to be linked to their territorial expression.

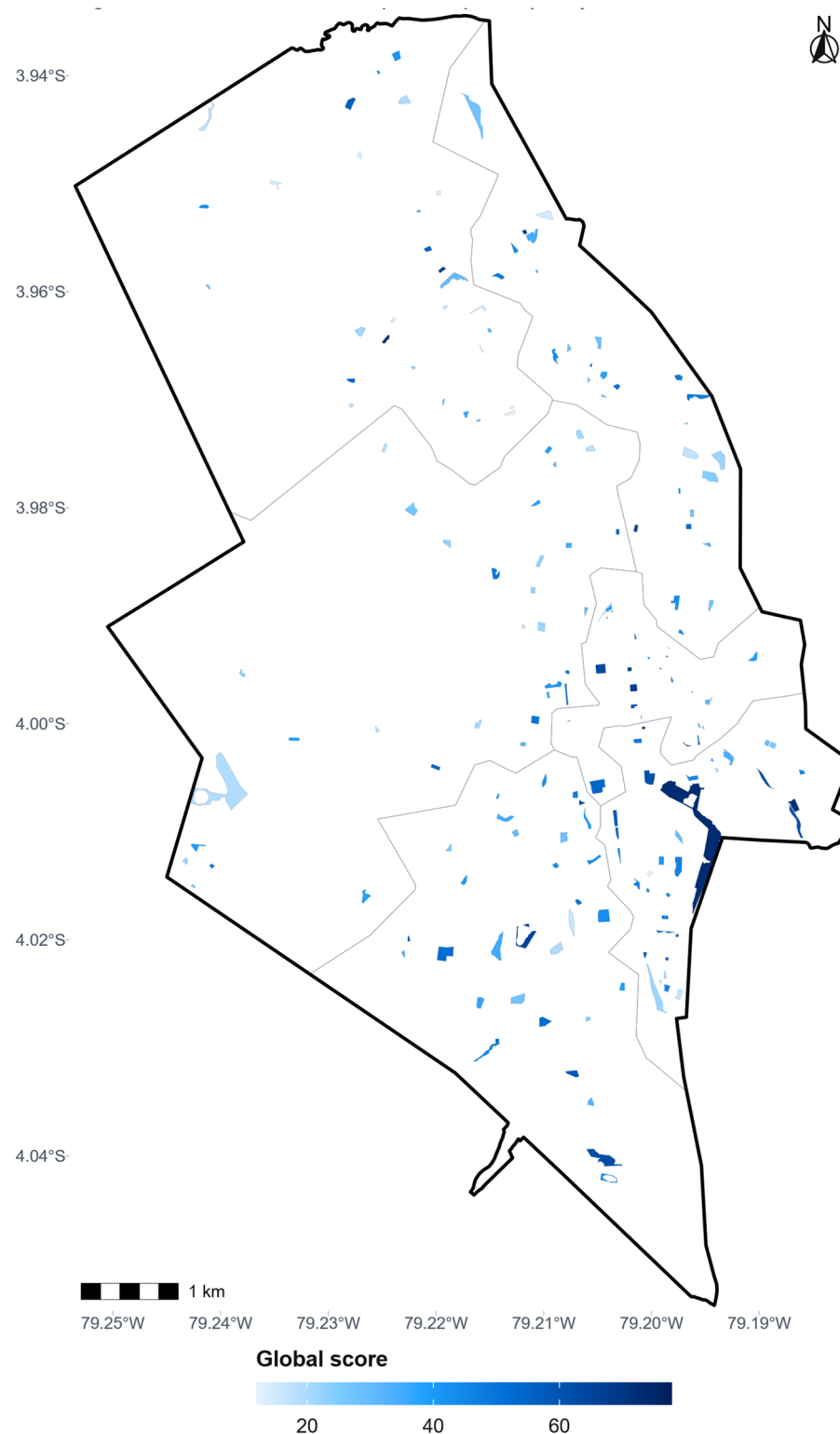


Figure 6. Spatial distribution of the global public space quality index.

As shown in Table 7, the Kruskal–Wallis test identified statistically significant differences in the global index among urban parishes and public space typologies. The effect size was smaller for parish grouping than for typology, indicating that public space type contributed more strongly to differences in global quality scores than parish grouping. Post hoc comparisons showed that parish-level differences were significant overall, but no pairwise parish comparison remained statistically significant after Bonferroni adjustment. In con-

trast, typological differences were observed between communal green areas and squares, communal green areas and neighborhood parks, and squares and neighborhood parks.

Table 7. Kruskal–Wallis test results for differences in global quality score.

Variable	Grouping Factor	Test Statistic (H)	df	p-Value	Effect Size ϵ^2	Post Hoc Summary
Global quality score	Parish	19.32	5	0.0017	0.081	No pairwise parish comparison remained significant after Bonferroni adjustment.
Global quality score	Typology	35.65	4	<0.001	0.178	Significant differences were observed between communal green areas and squares, communal green areas and neighborhood parks, and squares and neighborhood parks.

Note. The Kruskal–Wallis test was used to assess differences in the global quality score according to parish and typology. df = degrees of freedom. Effect size was estimated using epsilon-squared. Post hoc comparisons were performed using pairwise Wilcoxon tests with Bonferroni adjustment.

Public space typology also revealed a quality hierarchy. The urban park and district parks showed the highest global scores, followed by squares and neighborhood parks, whereas communal green areas presented the lowest average performance. However, the results for urban and district parks should be interpreted with caution because these typologies had a small number of observations.

3.4. Spatial Performance of the Index Dimensions

Figure 7a,b present the maps corresponding to the six evaluated dimensions. Figure 7a shows the structural dimensions, including functional, environmental, and safety scores, whereas Figure 7b shows the social-use dimensions, including cultural, recreational, and economic scores. The descriptive results show that functional and safety dimensions recorded higher mean values than cultural, recreational, and economic dimensions. The high frequency of zero values in the economic, recreational, and cultural dimensions indicates that many spaces lacked observable commercial activity, recreational infrastructure, or cultural-use conditions. Since zero values were treated as valid observations, these results reflect the actual absence of the evaluated attributes rather than missing information.

Table 8 presents the association structure between the index components and the global score. All dimensions showed positive correlations with the global index. The strongest association corresponded to the functional dimension, followed by cultural and safety. This pattern indicates that the global index was most strongly associated with functional conditions, while environmental and economic dimensions showed weaker rank-order associations with the overall score.

Table 8. Lower-triangle Spearman correlations among quality dimensions and the global index.

Variable	Functional	Environmental	Cultural	Recreational	Safety	Economic	Global
Functional	1.00						
Environmental	0.17	1.00					
Cultural	0.44	0.21	1.00				
Recreational	0.30	0.12	0.28	1.00			
Safety	0.34	0.12	0.34	0.26	1.00		
Economic	0.29	0.09	0.41	0.03	0.18	1.00	
Global	0.81	0.35	0.67	0.53	0.65	0.45	1.00

Note. Values represent Spearman's rank correlation coefficients. Correlations were rounded to two decimal places for presentation.



Figure 7. (a) Spatial patterns of structural public space quality dimensions. (b) Spatial patterns of social-use public space quality dimensions.

Figure 8 presents the Spearman correlation structure among the quality indicators. The strongest associations with the global index corresponded to the functional, cultural, and safety dimensions, confirming the main patterns reported in Table 8.

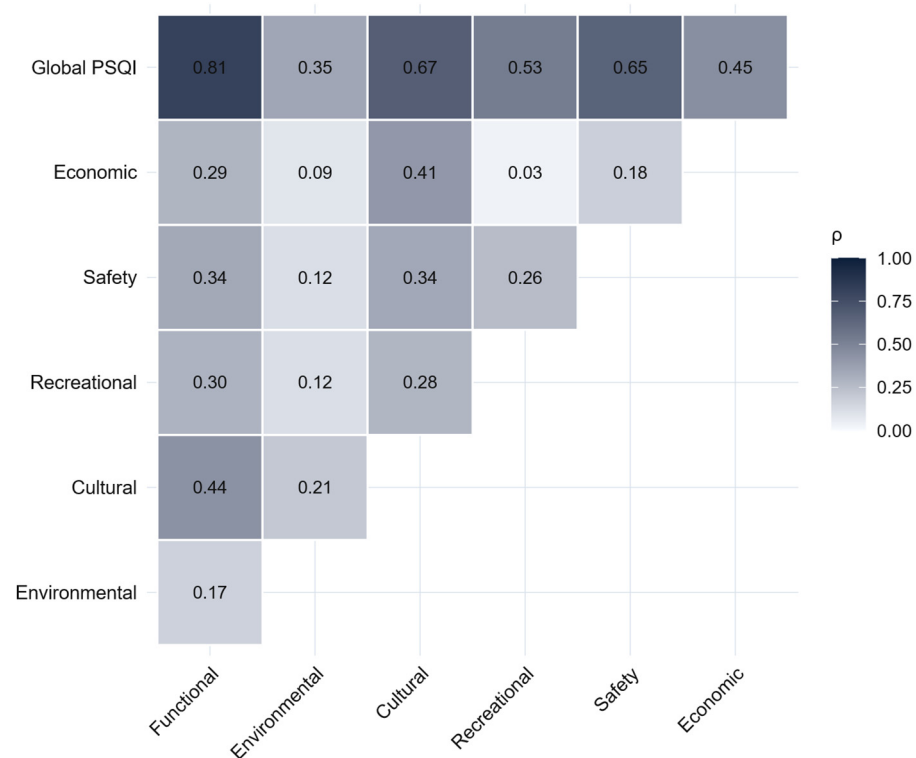


Figure 8. Spearman correlation matrix among quality indicators.

According to Table 9, two principal components had eigenvalues greater than 1. PC1 explained 38.06% of the total variance, while PC2 explained 17.29%; together, these two components accounted for 55.34% of the variance. Therefore, the PCA interpretation focused on the first two components, which summarized the main multivariate structure among the six quality dimensions. The remaining components are reported only as part of the full variance decomposition and were not interpreted as dominant components.

Table 9. Variance explained by the principal components of the quality dimensions.

Component	Eigenvalue	Variance Explained (%)	Cumulative Variance (%)
PC1	2.28	38.06	38.06
PC2	1.04	17.29	55.34
PC3	0.93	15.47	70.81
PC4	0.71	11.81	82.62
PC5	0.55	9.24	91.86
PC6	0.49	8.14	100.00

Note. PC = principal component. Variance explained and cumulative variance are expressed as percentages. Values were rounded to two decimal places for presentation.

A complementary Random Forest diagnostic was used to examine the relative importance of the dimensions in reproducing the global index structure. The highest permutation importance corresponded to the functional dimension (127.49), followed by safety (52.05), cultural (31.20), recreational (28.69), economic (12.98), and environmental (12.61). These results indicate that the global index was most strongly reproduced by functional and safety-related conditions. However, the Random Forest output was interpreted only as a

diagnostic check, not as causal evidence, because the global index was deterministically constructed from the six partial dimensions.

3.5. Spatial Prioritization of Intervention

Based on the deficit of the global index, calculated as the difference between the theoretical maximum value of the index and the observed score, a map of spatial intervention priority was generated. Figure 9 presents the territorial distribution of this prioritization. The spaces with the highest priority correspond to those with the lowest values of the global index.

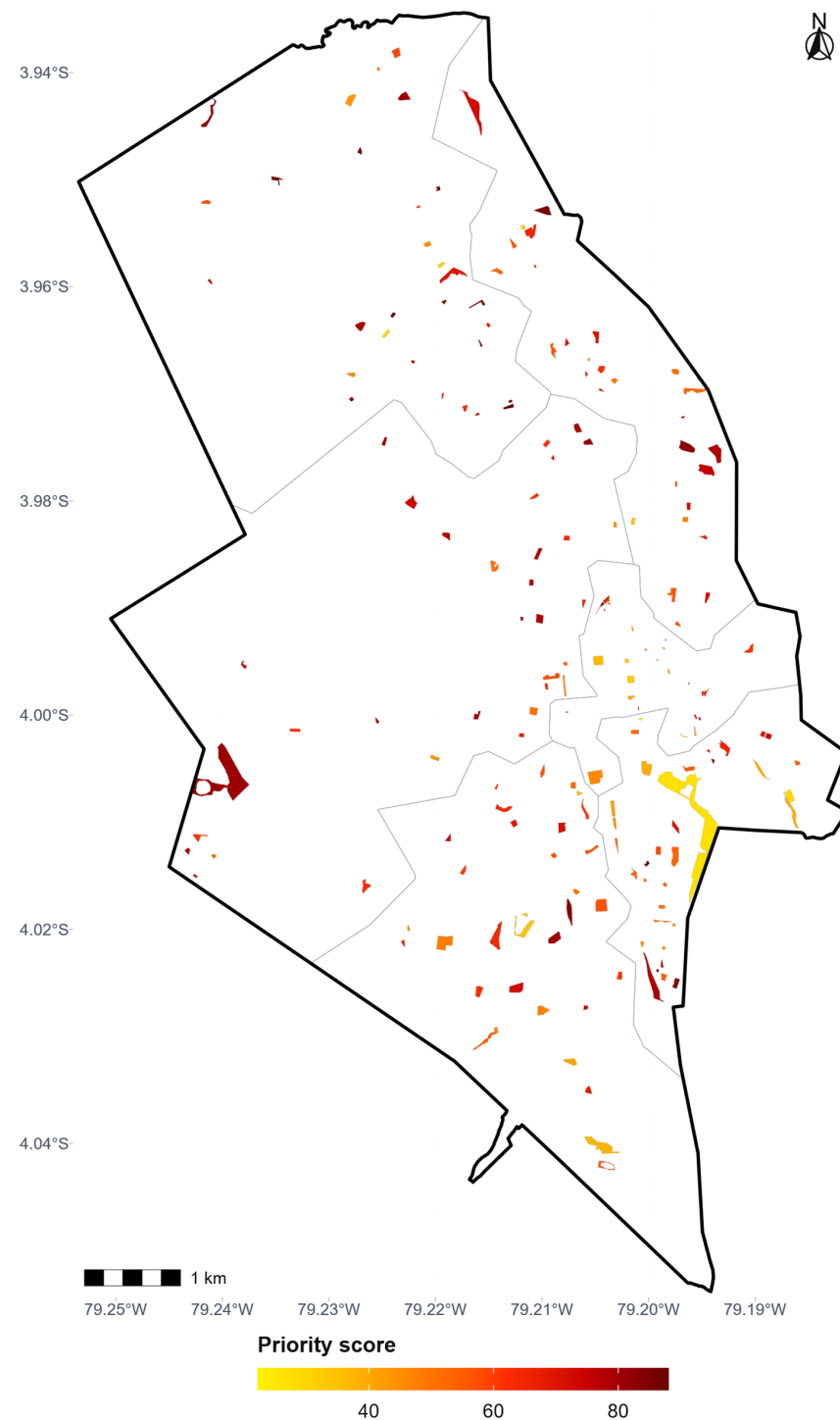


Figure 9. Spatial prioritization of intervention needs in public spaces.

Table 10 presents the first records prioritized according to the deficit of the global index. Among the spaces with the highest priority, BA-6-005, VC-1-004, and BA-1-012 were located at the top of the ranking. Several additional high-priority spaces were concentrated in Carigán, indicating that this parish contains multiple spaces with low global quality scores. The population column is reported only as contextual information and was not used to calculate the quality deficit or to order the records.

Table 10. Public spaces with the highest intervention priority according to the global index deficit.

Code	Parish	Typology	Population	Global Score	Quality Deficit (%)
BA-6-005	San Sebastián	Neighborhood park	331	12.00	88.00
VC-1-004	Carigán	Communal green area	340	12.25	87.75
BA-1-012	Carigán	Neighborhood park	177	13.25	86.75
BA-1-003	Carigán	Neighborhood park	80	13.50	86.50
BA-1-004	Carigán	Neighborhood park	174	13.50	86.50
BA-1-006	Carigán	Neighborhood park	149	13.50	86.50
BA-1-015	Carigán	Neighborhood park	53	13.50	86.50
BA-1-011	Carigán	Neighborhood park	60	13.75	86.25
VC-1-003	Carigán	Communal green area	466	14.25	85.75
VC-4-007	El Valle	Communal green area	85	14.50	85.50
PL-5-001	El Sagrario	Square	231	15.50	84.50
BA-1-009	Carigán	Neighborhood park	102	16.00	84.00
BA-6-014	San Sebastián	Neighborhood park	66	16.00	84.00
VC-3-004	Punzara	Communal green area	370	16.50	83.50
VC-6-003	San Sebastián	Communal green area	420	16.75	83.25
BA-2-007	Sucre	Neighborhood park	111	16.75	83.25
VC-4-001	El Valle	Communal green area	130	17.00	83.00
VC-1-006	Carigán	Communal green area	50	17.50	82.50
BA-4-005	El Valle	Neighborhood park	210	17.50	82.50
VC-1-008	Carigán	Communal green area	75	18.00	82.00

Note. The table presents the public spaces with the lowest global quality scores, ordered from lowest to highest score. The quality deficit was calculated as the difference between the maximum reference value of 100 and the observed global score. Population is reported as contextual information only and was not used to calculate or sort the quality deficit ranking. Values were rounded to two decimal places for presentation.

The multicriteria prioritization procedures were complemented with rankings derived from MADM methods. Specifically, the WSM, TOPSIS, and VIKOR methods were applied under different weighting scenarios, including original, equal, human-centered, environmental, entropy-based, and CRITIC-based weights. These results allowed the relative position of each public space to be contrasted under alternative multicriteria aggregation approaches.

Table 11 summarizes the consistency of the main MADM rankings. The high Spearman correlations between rankings indicate that the identification of priority spaces was generally stable under alternative multicriteria aggregation methods and weighting scenarios.

Table 11. Summary of ranking consistency across MADM methods and weighting scenarios.

Comparison	Spearman Correlation	Interpretation
WSM original weights vs. TOPSIS original weights	0.981	Very high agreement between rankings
WSM original weights vs. VIKOR original weight	0.952	Very high agreement between rankings
Original weights vs. equal-weight scenario	0.970	High stability under an alternative weighting assumption

Note. WSM = Weighted Sum Model; TOPSIS = Technique for Order Preference by Similarity to Ideal Solution; VIKOR = ViseKriterijumska Optimizacija I Kompromisno Resenje. Spearman correlations were used to evaluate rank agreement.

This analysis allowed the consistency of the prioritization to be verified by identifying spaces that maintained critical positions across several methods and weighting scenarios. In particular, spaces with lower global scores also tended to occupy unfavorable positions within the multicriteria rankings, reinforcing the robustness of the prioritization process. Thus, the MADM rankings are presented as a complementary validation of the classification obtained from the global quality index.

3.6. Local Spatial Autocorrelation of the Global Index

As shown in Table 12, the global index presented positive and significant spatial autocorrelation, with Moran's $I = 0.151$ and $p < 0.001$. At the local scale, significant clusters and spatial outliers were identified. Although most public spaces did not show statistically significant local spatial association, the presence of High–High, Low–Low, High–Low, and Low–High cases indicates that quality values are not entirely random in space and that specific local patterns can be detected.

Table 12. Global and local spatial autocorrelation of the global quality score.

Analysis Level	Statistic/Cluster	Value/ n	Expected Value	Variance	p -Value	Percentage (%)	Interpretation
Global Moran's I	Moran's I	0.151	−0.005	0.0016	<0.001	—	Significant positive spatial autocorrelation
Local Moran's I	High–High	15	—	—	—	8.20	High-quality spaces surrounded by high-quality neighbors
Local Moran's I	Low–Low	5	—	—	—	2.73	Low-quality spaces surrounded by low-quality neighbors
Local Moran's I	High–Low	6	—	—	—	3.28	High-quality spatial outliers in low-quality surroundings
Local Moran's I	Low–High	1	—	—	—	0.55	Low-quality spatial outlier in high-quality surroundings
Local Moran's I	Not significant	156	—	—	—	85.25	No statistically significant local spatial association

Note. Moran's I evaluates global spatial autocorrelation, whereas LISA identifies local spatial clusters and spatial outliers. Percentages were calculated using the 183 public spaces with valid global quality scores. High–High and Low–Low indicate spatial clustering, while High–Low and Low–High indicate spatial outliers. Values were rounded to three decimals for Moran's I and two decimals for percentages.

The territorial distribution of these results is presented in Figure 10. This figure shows the spaces with statistically significant local association, differentiating concentrations of high values, concentrations of low values, and spatial outliers.

High–High clusters presented a mean global index of 57.02 points, while Low–Low clusters recorded a mean value of 28.75 points. High–Low spaces corresponded to public spaces with comparatively high quality located in lower-quality surroundings, whereas the Low–High case represented a lower-quality space surrounded by higher-quality neighbors. These results distinguish generalized quality patterns from localized spatial outliers within the evaluated public space system.

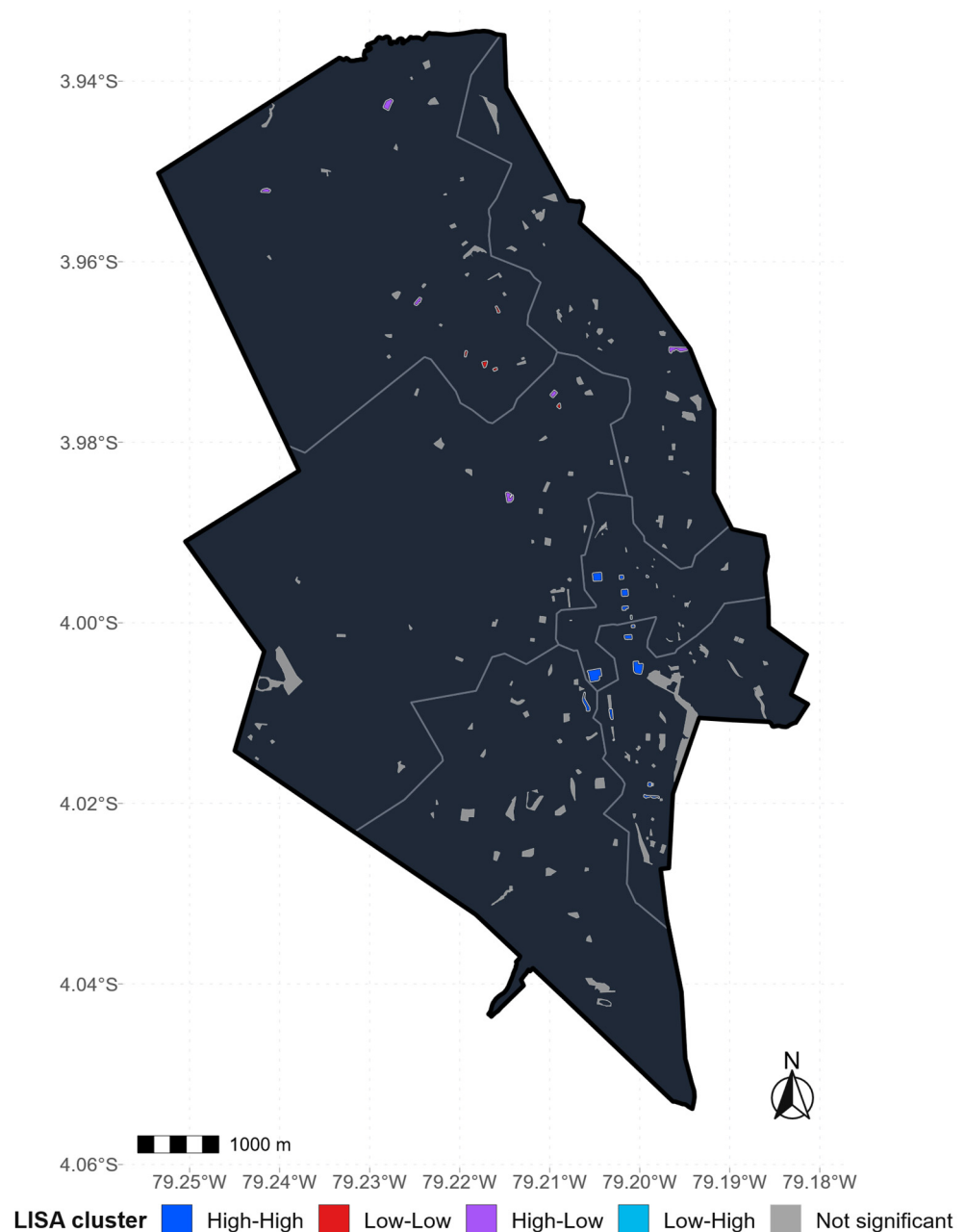


Figure 10. LISA spatial clusters of the global public space quality index.

4. Discussion

4.1. Multidimensional Public Space Quality and Territorial Inequalities

The findings of this study confirm that public space quality in Loja cannot be understood as a homogeneous urban condition, but rather as a multidimensional and spatially uneven phenomenon. The global index revealed a predominance of low and medium quality levels, while no evaluated space reached the very high-quality category. This pattern suggests that, although public spaces are present across the urban parishes, their functional, environmental, cultural, recreational, safety, and economic attributes are not sufficiently consolidated to produce high-quality urban environments throughout the city.

This result is consistent with previous studies that emphasize that public space quality depends not only on the availability of open areas, but also on their design, management, accessibility, safety, equipment, maintenance, and capacity to support social interaction [38]. From this perspective, the results contribute to the broader discussion on the difference

between the mere provision of public spaces and the effective provision of high-quality public spaces. In intermediate cities, where public space planning is often constrained by uneven urban growth, budget limitations, fragmented maintenance systems, and heterogeneous land-use patterns, the presence of parks, squares, or green communal areas does not necessarily guarantee equitable urban benefits.

The territorial differences observed among urban parishes also align with the environmental justice literature, which has shown that inequalities in green and public space provision are not limited to access or proximity, but also include differences in size, quality, amenities, and perceived usability [39,40]. In this study, the lower average performance of some peripheral or less consolidated parishes suggests that public space inequality may be associated with broader processes of urban expansion, uneven infrastructure provision, and differences in municipal investment or maintenance capacity. These conditions are particularly relevant in Latin American cities, where rapid urbanization and spatial fragmentation have historically produced unequal access to urban services, environmental amenities, and public facilities [41,42].

The fact that the sample was relatively balanced across parishes strengthens the interpretation that the observed differences are not only an artifact of sample distribution but rather reflect differentiated territorial conditions. Therefore, the index provides a useful diagnostic tool to identify where public space quality is comparatively weaker and where intervention efforts could have higher urban and social relevance.

4.2. Functional and Safety Dimensions as Structural Components of the Index

The strong association between the functional dimension and the global index indicates that accessibility, mobility, connectivity, and conditions for permanence are central components of public space quality in the evaluated context. This finding is consistent with studies that identify accessibility and mobility as foundational conditions for inclusive public spaces, since users cannot benefit from urban amenities if physical access, internal movement, or universal design conditions are limited [43,44].

In practical terms, this suggests that improving public space quality in Loja requires more than adding isolated amenities. Interventions should address basic functional conditions, such as seating, pedestrian access, ramps, internal circulation, absence of physical barriers, and connection with public transport. These elements are especially important in cities with topographic constraints, fragmented pedestrian networks, or limited universal accessibility standards, where small physical barriers can significantly reduce effective usability.

The safety dimension also showed a strong relationship with the global index. This is relevant because safety is both a physical and perceptual condition: lighting, visibility, surveillance, and the presence of people can influence whether public spaces are used, avoided, or perceived as neglected. Previous research has shown that safety, maintenance, and comfort are among the main determinants of park use and public space experience [45,46]. In this sense, the results suggest that safety-related interventions should not be treated as secondary improvements, but as structural components of public space quality.

The relatively better performance of safety compared with other dimensions may indicate that some basic elements, such as lighting or surrounding urban conditions, are more frequently present than cultural, recreational, or economic facilities. However, this does not necessarily imply that all public spaces are perceived as safe by users. Since this study was based on structured observation, future research should complement these findings with user perception data to distinguish between observed safety infrastructure and perceived safety.

4.3. Cultural, Recreational, and Economic Deficits as Indicators of Limited Urban Vitality

One of the most relevant interpretations of the results is that the lowest-performing dimensions were cultural, recreational, and economic. This pattern suggests that many public spaces function primarily as passive or residual urban areas, rather than as active environments capable of supporting cultural expression, social interaction, play, leisure, and local economic activity.

The cultural dimension is particularly important because public spaces are not only physical infrastructures; they are also arenas for symbolic expression, collective identity, and civic interaction. Previous research has emphasized that successful public spaces are those that support diverse activities and respond to social and cultural needs, rather than only providing open surfaces or green areas [47]. Therefore, the limited cultural performance identified in this study may reflect a lack of programmed activities, inadequate design for community events, or weak integration between public space planning and cultural policies.

Similarly, the low recreational performance indicates that many spaces may lack playgrounds, recreational furniture, or activity-supporting infrastructure. This finding is relevant because recreational facilities are associated with park use, physical activity, and social interaction, particularly among children, families, and older adults [48,49]. In this context, public space improvement should consider recreational infrastructure not as an accessory component, but as a key mechanism for transforming low-use spaces into active and inclusive urban environments.

The economic dimension also presented low values, suggesting limited presence of kiosks, vending, or small-scale commercial activity. This result can be interpreted in two ways. On the one hand, excessive or poorly regulated commercial activity can generate conflicts in public space. On the other hand, small-scale formal or semi-formal economic activity can contribute to vitality, surveillance, and longer use periods when adequately managed. Therefore, the low economic score should not be interpreted simply as a deficit to be corrected through commercialization, but as an indicator of limited multifunctionality and weak integration between public space and everyday urban life.

4.4. Spatial Clustering, Local Inequalities, and Intervention Prioritization

The positive and significant spatial autocorrelation indicates that public space quality is not randomly distributed across the city. Instead, there are localized patterns in which higher-quality spaces tend to be near other higher-quality spaces, and lower-quality spaces tend to be near other lower-quality spaces. This finding is important because it suggests that public space quality is influenced by territorial conditions and neighborhood-level processes, rather than by isolated characteristics of individual spaces.

The identification of High–High and Low–Low clusters provides evidence of spatial concentration. High-quality clusters may correspond to better consolidated urban environments, areas with higher levels of public investment, more central locations, or spaces with stronger functional and environmental attributes. In contrast, Low–Low clusters may indicate areas where multiple deficits overlap, such as weaker infrastructure, limited recreational provision, lower maintenance, or reduced integration with surrounding urban systems.

This interpretation is consistent with studies showing that spatial inequities in green and public space systems are often associated with broader urban inequalities, including differences in accessibility, neighborhood consolidation, socioeconomic conditions, and planning priorities [50,51]. The case of Loja contributes to this discussion by showing that quality-based spatial inequality can be detected even in an intermediate Latin American city, where public space research is still less abundant than in large metropolitan areas.

The prioritization approach used in this study reinforces the practical relevance of the index. By combining global quality deficits with spatial representation and multicriteria ranking procedures, the study provides an evidence-based framework for identifying spaces that require intervention. This is consistent with recent work suggesting that urban green space planning should move beyond simple proximity indicators and incorporate multidimensional criteria, quality attributes, and equity-oriented decision tools [52].

From a planning perspective, the priority map and ranking outputs can support phased investment strategies. Rather than distributing interventions uniformly across the city, local governments could identify spaces where multiple deficits converge and where improvements could reduce territorial inequalities. Such an approach is especially relevant in contexts with limited municipal resources, where prioritization is necessary to maximize social and spatial impact.

4.5. Planning Implications for Intermediate Latin American Cities

The results have several implications for urban planning in intermediate Latin American cities. First, the study shows that public space assessment should incorporate quality and not only quantity or spatial availability. A city may have a relatively broad network of public spaces, but if many of them lack accessibility, recreation, cultural functions, environmental quality, or basic amenities, their contribution to urban well-being remains limited.

Second, the findings suggest that quality deficits should be addressed through differentiated intervention packages. Spaces with functional deficits may require accessibility improvements, ramps, pedestrian connections, benches, and removal of internal barriers. Spaces with environmental deficits may require tree planting, green area restoration, and maintenance strategies. Spaces with recreational or cultural deficits may require playgrounds, flexible event areas, cultural programming, and inclusive furniture. This differentiated approach is more useful than applying a single standard intervention model to all spaces.

Third, the study highlights the importance of integrating spatial analysis into public space policy. The use of GIS, spatial autocorrelation, and multicriteria ranking provides a more precise understanding of where deficits are concentrated and how intervention priorities can be spatially organized. This is particularly valuable in intermediate cities, where technical planning tools are often less developed than in larger metropolitan areas, but where rapid urban change creates increasing demand for evidence-based decision-making.

Finally, the findings suggest that public space improvement should be understood as part of a broader strategy of urban equity. Improving low-quality public spaces can contribute not only to environmental and recreational benefits, but also to social cohesion, neighborhood identity, perceived safety, and everyday quality of life. However, interventions must be carefully designed to avoid reinforcing unequal patterns of investment or producing improvements only in already consolidated areas.

4.6. Study Limitations

This study has several limitations that should be acknowledged. First, the quality index was constructed from structured observational data, which provides comparability across spaces but does not fully capture user perceptions, satisfaction, frequency of use, or subjective experiences of safety, comfort, and attachment. Although the field instrument included observable attributes, future assessments should incorporate surveys or participatory methods to complement the physical evaluation with user-based evidence.

Second, the weighting structure of the index was based on a normative-methodological criterion. Although the study included alternative weighting scenarios and multicriteria methods to assess the robustness of prioritization, the original weights still reflect a prede-

financed conceptual decision. Future studies could compare these weights with expert-based, community-based, or statistically derived weighting schemes.

Third, the analysis was based on data collected in two survey periods, 2023 and 2024. Public spaces are dynamic environments, and their quality may change over time due to maintenance, deterioration, informal use, new investments, or changes in surrounding land use. Therefore, the results should be interpreted as a diagnostic assessment for the evaluated period rather than as a permanent classification of each space.

Fourth, the spatial analysis used the available public space geometries and a k-nearest-neighbor structure for autocorrelation. While this approach allowed local spatial associations to be identified, alternative spatial weights matrices—such as distance bands, contiguity-based structures, or network-based accessibility measures—could produce complementary interpretations.

In addition, the parish reference zones used in the cartographic outputs should be interpreted as spatial reference units for visualization and territorial interpretation, rather than as explanatory socioeconomic units. Therefore, parish-level differences were analyzed as descriptive territorial patterns and not as causal effects of administrative or socioeconomic conditions.

Finally, the study was conducted in a single intermediate Latin American city. Although the methodological framework can be replicated in other urban contexts, the specific scores, spatial patterns, and intervention priorities are context-dependent and should not be generalized without considering local urban morphology, governance structures, socioeconomic conditions, and public space planning practices.

4.7. Future Research Directions

Future research should expand the methodological framework in several directions. First, user perception surveys should be incorporated to compare observed quality with perceived quality. This would allow the analysis to identify mismatches between technical evaluations and everyday experiences of users.

Second, future studies could integrate socioeconomic and demographic variables at the neighborhood level to evaluate whether lower-quality public spaces are associated with vulnerable populations, lower-income areas, or peripheral urban expansion. This would strengthen the environmental justice dimension of the analysis.

Third, longitudinal monitoring should be developed to assess how public space quality changes over time. Repeated evaluations would make it possible to measure the effects of maintenance, public investment, urban growth, or deterioration processes.

Fourth, future research could incorporate network-based accessibility indicators, considering walking routes, slope, sidewalk quality, barriers, and public transport connectivity. This would improve the interpretation of functional access, especially in cities with complex topography.

Fifth, the multicriteria prioritization framework could be extended by incorporating participatory weighting procedures involving residents, planners, local authorities, and community organizations. This would make it possible to compare technical, institutional, and community priorities.

Finally, future studies could test the transferability of the proposed index in other intermediate cities in Ecuador or Latin America. Comparative applications would help determine whether the observed patterns are specific to Loja or reflect broader challenges in public space quality, spatial inequality, and urban planning in intermediate Latin American cities.

5. Conclusions

This study aimed to evaluate spatial inequalities in the quality of urban public spaces in Loja, Ecuador, through a GIS-based multi-attribute composite index integrating functional, environmental, cultural, recreational, safety, and economic dimensions. The results show that public space quality in the city is predominantly concentrated at low and medium levels, indicating that the existence of public spaces does not necessarily imply the presence of consolidated, accessible, multifunctional, and high-quality urban environments. The global index and its dimensions revealed marked differences among urban parishes and typologies, with functional and safety conditions playing a central role in the overall quality structure, while cultural, recreational, and economic components reflected weaker levels of urban vitality and multifunctionality.

The spatial analysis confirmed that public space quality is not randomly distributed across the urban area, but follows differentiated territorial patterns, including local clusters and spatial outliers. These findings demonstrate the usefulness of combining composite indicators, GIS-based analysis, spatial autocorrelation, and multicriteria prioritization to support evidence-based urban planning. The proposed methodological framework provides a replicable tool for diagnosing observable public space quality, identifying priority intervention areas, and guiding more equitable investment decisions in intermediate Latin American cities. Overall, the study highlights the need to move beyond quantitative provision indicators and incorporate quality, spatial distribution, and multidimensional performance as central criteria in public space planning.

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Abbreviations

The following abbreviations are used in this manuscript:

CV	Coefficient of Variation
CRITIC	Criteria Importance Through Intercriteria Correlation
GIS	Geographic Information System
IQR	Interquartile Range
LISA	Local Indicators of Spatial Association
MADM	Multiple Attribute Decision-Making
PCA	Principal Component Analysis
Q1	First Quartile
Q3	Third Quartile
SD	Standard Deviation
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UTM	Universal Transverse Mercator
UTPL	Universidad Técnica Particular de Loja
VIKOR	ViseKriterijumska Optimizacija I Kompromisno Resenje
WGS 84	World Geodetic System 1984
WSM	Weighted Sum Model

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