

EXTRACTION OF GEOSPATIAL INFORMATION FROM OPEN-SOURCE DATA PLATFORMS FOR URBAN ENVIRONMENT ANALYSIS OF HEALTH- INFLUENCING URBAN INDICATORS – CASE STUDY BRATISLAVA PETRŽALKA

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Abstract

This study examines whether freely available open-source geospatial data can be used to calculate urban indicators that affect public health and environmental sustainability. The main aim is to assess the availability, structure, and resolution of such datasets in the Slovak context, using the Petržalka district of Bratislava as a case study. The methodology includes the use of desk research and GIS-based analysis to identify suitable indicators and calculate their values. Key findings highlight limitations in data granularity and consistency across platforms but also confirm that several indicators - such as tree canopy cover, built-up area density, and access to green spaces - can be extracted. The results underline the urgent need for better access to geospatial data infrastructure in Slovakia and support the potential use of open-source data in developing future composite indicators.

Keywords

Urban planning, geospatial analysis, health-influencing urban indicators, public health, urban design

1 INTRODUCTION

Urbanisation and the rising burden of lifestyle-related diseases have prompted the integration of health perspectives into urban design and planning. This shift reflects a growing recognition of the nexus between the built environment and human health, whereby specific urban design parameters - such as density, greenery, or building height - can directly or indirectly influence both physical and mental well-being.

In the Slovak context, however, there is currently no centralised or standardised database of urban design indicators known from the literature to influence health. One of the main reasons is the absence of systematically collected input data for indicator calculation at the local level, which limits the implementation of evidence-based urban health assessments.

The main aim of this study is to explore whether freely available open-source geospatial platforms can fill this data gap. Specifically, the study examines whether such platforms contain relevant input data in a form, structure, level of detail, and resolution sufficient to derive and calculate selected urban design indicators. Only after assessing the availability of such relevant data will it be possible to evaluate whether these indicators can be quantified meaningfully and included in further geospatial analyses related to urban health and the quality of the built environment.

The objectives of the study are:

- To review the methods and techniques used for calculating urban design indicators related to human health in the built environment.
- To identify the required level of detail and structure of data needed to analyse the built environment through health-affecting urban design indicators.

- To determine what input data are currently available for Slovakia, and their limitations for calculating the values of selected health-affecting urban design indicators.
- To investigate how the identified freely available input data for Slovakia can be used to calculate these urban design indicators.

In recent years, several composite indices and urban health tools (e.g. the City Stress Index, Urban Health Index and Environmental Stress Index) have been developed to assess the health impacts of the built environment. However, these frameworks typically rely on harmonised, high-resolution datasets – not currently available in Slovakia - and they often exclude structural urban form indicators such as parking surface share, Floor Area Ratio, or building height, despite their importance for human-scale experience and psychological well-being. This study responds to that gap by exploring whether open-source spatial datasets can provide a sufficient basis for calculating such indicators individually, with the potential to be integrated into future composite frameworks.

In addition, the study aims to develop a scalable and transferable methodology that can be applied across Slovakia. This would allow for a more robust evaluation of the nexus between population health outcomes and specific forms of the built environment in Slovak cities. Therefore, the focus is placed on methods that support replication and upscaling in future research and planning efforts.

LITERARY OVERVIEW / DESCRIPTION OF THE PRESENT STATE

The increasing prevalence of chronic, lifestyle-related diseases such as cardiovascular disorders, obesity and respiratory conditions, alongside mental health issues, has made public health a critical concern in urban environments. Historically, urbanism and spatial planning have prioritised economic growth and land use efficiency, often overlooking the profound impact of spatial structure on health outcomes [3], [4], [5], [6].

As research continues to reveal strong links between urban form and health, there is a growing call to integrate health-sensitive urban design indicators into planning practice [7], [8]. This is particularly urgent as chronic illnesses reach pandemic levels, urging cities to consider how spatial configuration shapes residents' well-being.

Numerous studies have used diverse analytical methods to explore how specific health-influencing urban design indicators - such as green space, density, or accessibility - affect physical and mental health [9]. Geospatial analysis has emerged as a central tool in such research, enabling the mapping and assessment of spatial characteristics related to urban health and environmental sustainability. However, far fewer studies focus on the quality of input data used in these analyses, or the methods used to collect them, despite their critical role in ensuring the accuracy, comparability, and reproducibility of results.

According to the literature, key urban indicators relevant to health include the proportion of green space, tree canopy cover, parking areas, accessibility to greenery, built-up area density, Floor Area Ratio (FAR), building height, and population density per m² [14], [15], [16], [17]. These indicators shape environmental exposure, air quality, noise levels, and daylight access—factors closely tied to health [14], [15], [16], [17], [18], [19], [20]. Balanced urban form, adequate greenery and proximity to open spaces contribute to social cohesion and lower stress [21].

Internationally, several composite indices have been developed to integrate these indicators into a single metric for urban health planning. However, many of these tools focus on greenery and pollution, often neglecting structural form indicators such as FAR or parking surfaces [49]. Yet, such metrics fundamentally influence human perception of space, urban legibility, and psychological comfort, especially in post-socialist contexts with a prevalence of prefabricated panel housing blocks [49].

2 METHODOLOGY

While this article focuses on quantitative indicators derived from geospatial datasets, a holistic evaluation of the nexus between urban form and population health must also include qualitative components - such as questionnaire surveys, Kevin Lynch-based mental mapping, and biosensor measurements - to capture perception, behaviour, and physiological responses. The indicators selected were based on their theoretical relevance to urban design and are recognised as valid proxies for health and environmental stressors.

The methodology followed the study's objectives. First, the existing methods and techniques for obtaining the input data needed to calculate relevant indicators were reviewed via desk research. Then, key open-access datasets

were assessed - Copernicus, Sentinel-2, OpenStreetMap, municipal land-use data, ZBGIS, and EUBUCCO – based on granularity, thematic accuracy, and resolution. Where necessary, proxy or alternative sources were used.

A comparative analysis evaluated data discrepancies and suitability. Indicators were calculated and spatially analysed in Petržalka using standard GIS techniques and compared to international benchmarks (e.g., WHO, Konijnendijk). No normalisation or weighting were applied, with the focus being instead on basic feasibility and spatial realities.

A separate satellite classification (Sentinel-2, Sept 2024) was also performed using a supervised SVM algorithm in ArcGIS to classify land cover (trees, grass, impervious surfaces) and compared with outputs from OSM, ZBGIS, and Copernicus to assess consistency and completeness.

Health-influencing urban design indicators

Proportion of Green Space

Green spaces support mental and physical health by offering recreational opportunities and improving air quality [22]. Kabisch & Haase [23] used NDVI to monitor green space in European cities, emphasising the WHO's recommendation that functional green areas should exceed 0.5–1 hectare [24]. Green space can be calculated via urban planning files or satellite imagery, depending on data resolution [25], [26], [27]. High-resolution satellite imagery (10–30 m) and NDVI are useful for such classifications. In this study, green space was first classified using Sentinel-2 (Sept 2024) and SVM in ArcGIS, identifying trees and grass. Second, Copernicus Urban Atlas (2018) categories were used to quantify predefined green areas. Both methods were compared for consistency and accuracy.

Proportion of High Green - Tree Canopy Cover

Tree canopies regulate temperature, improve air quality, and reduce stress-related health problems [28], [29]. Lidar is ideal for measuring canopy height and density [30]. Tree canopy was calculated using Copernicus HRL Forest Type (2018), a custom Sentinel-2 SVM classification (Sept 2024), and OSM (via Overpass Turbo, using tags like `natural=tree`). The Copernicus dataset had harmonised European coverage, while the OSM data were spatially inconsistent.

Walking Distance to Green Spaces

Access to green spaces fosters physical activity and mental well-being [34], [35], [36], [37]. The WHO recommends all inhabitants of urban areas should have access to ≥ 0.5 hectare of green space within 300 m of their homes [24]. This analysis applied the WHO's distance criteria using GIS buffers but used buildings (not residents) as proxies due to a lack of gridded population data. Residential buildings were assessed based on spatial proximity to green spaces.

Proportion of Car Parking Areas

High parking surface share correlates with sedentary lifestyles and reduced green space [15], [31], [32], [33]. Parking surfaces were extracted from ZBGIS and OSM. Satellite classification was ruled out due to the difficulty of distinguishing between paved surfaces (e.g., sports fields). Parcels labelled as car parks were verified visually and cross-checked with OSM. The proportion was calculated from the total district area, excluding street parking.

Density of Built-Up Areas

High built-up density may increase psychological stress due to limited green/public space [40], [41]. Urban sprawl and congestion also pose sustainability challenges [42], [43]. Built-up density was calculated using the Copernicus Urban Atlas and boundaries from the National Geoportal, ZBGIS, and the Bratislava planning file. Total built-up land was divided by the district's area to determine the proportion.

Floor Area Ratio (FAR)

FAR quantifies building volume intensity and is linked to crowding and open space provision [44], [45]. The FAR was calculated using building footprints and average height (assumed floor height: 3 m) based on typical Petržalka construction patterns.

Building Height

Building height affects human scale, sunlight, and psychological comfort [46]. Mid-rise buildings (4–6 floors) enhance walkability and cohesion. Heights were estimated from Copernicus raster data and EUBUCCO. The

values were averaged and converted into floors (3 m per floor). These results also served as the basis for FAR estimation. Lidar was unavailable for Slovakia.

Population density per hectare of built-up area

High residential density is linked to psychological stress due to overstimulation [48]. Built-up boundaries (from ZBGIS and the Bratislava spatial plan) were used to estimate density. The number of residents was proportionally distributed over the floor area, calculated by dividing the building height by 3 m and multiplying by the footprint area.

3 URBAN INDICATOR ANALYSIS: CASE STUDY BRATISLAVA-PETRŽALKÁ

Description of the case study area

Petržalka, a district of Bratislava, is a prefabricated panel housing estate emblematic of the typical urban structures found in most Slovak cities. It is the largest urban district of Bratislava and the largest housing estate in Slovakia, built mainly in the 1970s and 1980s.

The character of Petržalka reflects the urban and social stance of the socialist era. The urban layout of the housing estate consists of large residential blocks built from prefabricated concrete panels in a standardised manner. These structures, which mostly vary in height from four to twelve storeys, provide housing for tens of thousands of people and give the district its distinctive appearance. The layout follows the principles of modernist urbanism, characterised by large-scale superblocks and extensive residential zones.

The urban layout of Petržalka presents significant navigation challenges, characterised by the fragmented structure of a vertical city that often lacks a cohesive human-scale design. Moreover, the area suffers from limited barrier-free accessibility and inadequate provision of functional public spaces, hindering community cohesion and interaction.

However, due to the scarce housing opportunities in Bratislava, Petržalka stands as a socially diverse neighbourhood with residents from all social backgrounds and generations seeking affordable housing.

3 RESULTS

Based on the outlined methodology, eight urban design indicators relevant to public health were calculated for the Petržalka district in Bratislava. Each indicator was derived from freely available open-source geospatial datasets and, where applicable, validated or compared using complementary data sources. The results are presented individually and evaluated against recommended thresholds from the World Health Organization and peer-reviewed literature to assess their adequacy in the local context.

Proportion of Green Space: Based on satellite classification, grass-covered areas account for 6.68% and parks 11.67% of the district. According to the Copernicus Urban Atlas, green space makes up 8.67%, and large parks (>1 ha) 9.55%.

Tree Canopy Cover: Copernicus estimated canopy cover at 14.62%, while custom Sentinel-2 classification gave 21%. OSM data was sparse and unreliable.

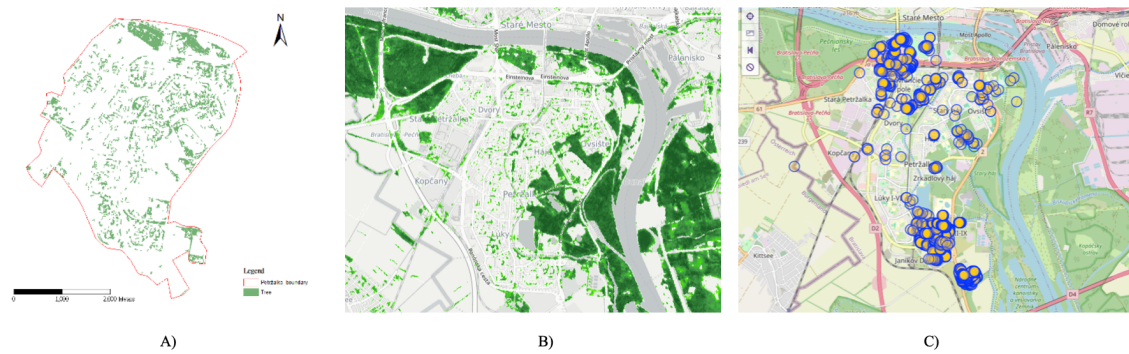


Fig. 1 Visual comparison of tree canopy data from multiple sources. A) Extraction of tree canopy from Sentinel-2. B) Extraction of tree canopy from Copernicus Urban Atlas. C) Extraction of tree canopy from OSM.

Walking Distance to Green Spaces: Using a 300 m buffer around green areas >1 ha, only 14.78% of buildings fall within the accessible zone due to the lack of high-resolution population data.

Proportion of Parking Areas: Satellite data could not differentiate between types of paved surfaces. ZBGIS was used as the primary source, supported by OSM tags. The total parking area covers 6.26%, of which 5.89% is ground-level.

Density of Built-Up Area: Using ZBGIS and planning boundaries (1504.42 ha), built-up density is 22.53%. The Geoportal boundary (833 ha) was shown as inadequate for calculation, as only 62.7% of the existing buildings were situated within the boundary.



Fig. 2 Visual comparison of the built-up area boundary from multiple sources. A) Built-up area boundary manually redrawn from Bratislava urban planning file. B) Built-up area boundary downloaded as GIS compatible layer from National geoportal.

Building Height: EUBUCCO data shows an average of 12.46 m (4.15 floors); residential buildings average 22.18 m (7.39 floors). ZBGIS gives a 2-floor average.

Floor Area Ratio (FAR): FAR derived from ZBGIS equals 1.96; from EUBUCCO data, it is 0.68.

Population Density per m² of Built-Up Area: Based on the 1504.42 ha boundary, density is 74.98 inhabitants/ha.

Tab. 1 Summary of findings.

Category	Value (m ² or m) / % or different	Optimum Values Given by the Literature	Evaluation
Tree Canopy Cover	2 199 300.17 / 14.62%	30% (Konijnendijk, 2021)	Below Optimal
Grass / low greenery	1 304 415.67 / 8.67–11.67% / 8.6 7%–9.55%	—	Below Average
Walking Distance to Green Spaces	2 224 157.15 / 14.78%	WHO: Green space within 300 m of all residents	Partially Sufficient
Density of Built-Up Area	3 388 848.85 / 22.53%	Balanced urban density should range between 30–50% built-up	Moderate Density
Proportion of Parking Areas	941 966.78 / 6.26%	Ground-level parking should not exceed 3–5%	Above Optimal
Parking Area (ground level only)	886 276.06 / 5.89%	Maximum 3–5%	Above Optimal
Building height	4–14	Optimum: 4–6 floors for human- scale urbanism	Somewhere optimal / somewhere above optimal
FAR	0.68 / 1.96	Balanced FAR: 1.5–2.5 in dense urban areas	Within Recommended Range
Population Density per m ² of Built-Up Area	74.4 inhabitants/ha	Optimal population density varies, but high density can increase stress if not balanced with green spaces	Moderate Density

4 DISCUSSION

This study explored whether freely available geospatial data can be used to calculate urban design indicators relevant to health. The findings directly reflect and expand upon concerns raised in the literature about the growing need to integrate spatial indicators into health-sensitive urban planning, especially as the prevalence of chronic lifestyle-related diseases is rising. While much of the research has focused on how urban form influences health outcomes, fewer studies have addressed the foundational step of acquiring reliable and comparable geospatial input data. This study responds to that gap by testing the feasibility of using open-source data for this purpose in the Slovak context. The results confirm that open-source platforms do offer sufficient data for several key indicators, such as green space, tree canopy cover, building density and parking surfaces, but with important caveats. Data completeness, format, resolution, and thematic classification varies considerably across platforms, often requiring combination, approximation, or reclassification.

One of the most striking outcomes of this research is the inconsistency in values across different sources for the same indicator. For example, estimates of tree canopy cover differed by more than 6 percentage points between the Copernicus HRL and Sentinel-2 classifications. Similarly, green space coverage appeared fragmented in the satellite-derived classification compared to the Urban Atlas. These differences are not merely technical – they have consequences for spatial analysis and policy recommendations. Therefore, cross-validation and triangulation of sources were essential steps to determine which data were suitable for health-relevant analysis.

Two different built-up area boundaries were used to calculate the density of the built-up area – one published on the National Geoportal (area 833 ha) and the other redrawn from the spatial planning documentation for Bratislava from 1990 (area 1504.42 ha).

The comparison also showed that the boundary of the built-up area of Petržalka from the Geoportal does not include 1/3 of the existing buildings, which causes an underestimation of the built-up indicator. In contrast, the boundary from the urban planning file of Bratislava more accurately encircles the entire urbanised area, even though it had to be manually redrawn, which may cause several precision issues. In the case of the analysed area (Petržalka), these differences are particularly pronounced - several parts of the settlements remain outside the formally registered boundary.

This situation highlights the need for critical handling of official data layers, as well as the importance of updating planning documents into a digitally accessible form. From a research perspective, residents' mental experience of the urban environment must not be based on administrative boundaries, but on their everyday experience of urban space.

The discussion of individual indicators shows that each required a specific methodological solution. Parking areas could not be reliably classified via remote sensing due to surface ambiguity and were instead extracted from cadastral data and OpenStreetMap. Building height and floor area calculations relied on EUBUCCO but were checked against national open data to assess internal variation. For accessibility to green space, the lack of gridded population data led to the decision to analyse proximity based on actual physical buildings rather than per capita, acknowledging this as a limitation.

Tab. 2 Comparative analysis of data sources used.

Indicator	Sources Compared	Range of Results / Notes	Final Source Selected
Tree Canopy Cover	Copernicus HRL, Sentinel-2 classification, OSM	14.62% (Copernicus) vs ~21% (Sentinel-2); OSM incomplete and spatially inconsistent	Copernicus HRL
Proportion of Green Space	Copernicus Urban Atlas, Sentinel-2 classification	Urban Atlas excluded fragmented/informal greens; Sentinel-2 more detailed but unstructured	Copernicus Urban Atlas
Car Parking Area	ZBGIS cadastral data, OSM, satellite imagery	Satellite unable to distinguish surfaces; OSM had inconsistencies; ZBGIS legally grounded	ZBGIS + OSM cross-verified
Built-Up Area Density	ZBGIS, Bratislava planning data, National Geoportal	ZBGIS/planning files: 22.53%, Geoportal: inadequate due to differences in boundary definitions	ZBGIS + Bratislava planning file
Building Height / Floors	EUBUCCO, ZBGIS floor counts	Avg. 12.46 m / 4.15 floors vs 22.18 m / 7.39 floors for residential buildings (EUBUCCO)	EUBUCCO
Floor Area Ratio (FAR)	EUBUCCO heights + building footprints	Derived via estimated floors × footprint / total area; assumptions about uniformity noted	EUBUCCO

Indicator	Sources Compared	Range of Results / Notes	Final Source Selected
Green Space Accessibility	ZBGIS, OSM, Copernicus	14.78% of buildings within 300 m; Copernicus polygons lacked accessibility info; population grid missing	ZBGIS + OSM polygons

What emerges from this effort reflects the Slovak context, where no unified, centralised database of urban indicators exists. Moreover, partial studies and localised calculations in this area are largely absent, leaving little empirical foundation upon which further spatial health analyses can build. The comparative analysis of available open data sources thus serves as a diagnostic tool for what is possible, what is missing, and where investments in data infrastructure are needed.

In terms of research objectives, the study successfully reviewed relevant calculation methods (Objective 1), identified necessary data types and structures (Objective 2), mapped the current availability and gaps in Slovak datasets (Objective 3), and tested the usability of those data in practice (Objective 4). While not all indicators could be calculated with perfect precision, the study proves the feasibility of developing a baseline urban health dataset using only open-source inputs.

Finally, this work contributes to the broader call for more transparent and reproducible spatial health analysis. It underscores the importance of aligning indicator selection with data availability, adapting methods to the local urban context, and critically assessing source reliability. These steps are vital for evidence-based urban planning in Slovakia and comparable regions, especially given the limited integration of urban form indicators into existing composite health indices. As the literature suggests, indicators such as parking share, FAR and building height – often overlooked – play a critical role in shaping human-scale urbanism and psychological comfort, especially in post-socialist housing estates common across Central and Eastern Europe.

Implications for Further Research

This study opens several avenues for future research. First, urban indicators should be explored through longitudinal and comparative analyses to capture their change over time and across different urban settings. Second, integrating perception-based data such as mental mapping, biosensors, and surveys into geospatial studies can link urban form with lived experience. Third, there is a need to develop context-specific composite indices reflecting both structural and experiential aspects of the urban environment, which is particularly relevant in post-socialist cities. Finally, improving data harmonisation and spatial resolution will require interdisciplinary cooperation and policy support to strengthen data quality, interoperability, and accessibility.

5 CONCLUSION

This study investigated whether freely available open-source geospatial data can be used to calculate health-influencing urban design indicators in the Slovak context, focusing on Bratislava–Petržalka as a case study. It demonstrated that several key indicators—such as green space proportion, tree canopy cover, built-up area density, building height, Floor Area Ratio (FAR), and proximity to green areas—can be measured using open data. However, the analysis also revealed critical limitations related to data completeness, resolution, and thematic consistency, which directly affect indicator accuracy and comparability.

Comparative analysis across multiple data sources showed substantial discrepancies, particularly in the estimation of tree cover, green space, and built-up surfaces. These inconsistencies highlight the need for methodological transparency and data triangulation when applying open-source datasets to urban health research. The study thus underscores both the promise and the complexity of using open data in regions like Slovakia, where no unified, centralised system for spatial health indicators currently exists.

Rather than applying a composite health index—which often requires harmonised and high-resolution datasets not available in this context—the study focused on individual indicator analysis. This approach proved more feasible and better suited to reflecting the unique structural and environmental characteristics of post-socialist urban areas.

Moreover, the exclusion of important urban form metrics (such as parking area share, FAR, and building height) from many existing composite indices further justified this choice.

By identifying gaps, testing methodologies, and evaluating feasibility, this research lays the groundwork for the future development of a context-specific urban health index tailored to Slovak and Central European conditions. It contributes to a growing body of literature advocating for data-informed, health-sensitive spatial planning – especially vital in light of rising chronic disease burdens and the need to design cities that promote mental and physical well-being.

Ultimately, the study affirms that while open-source geospatial platforms are a valuable resource for measuring urban health indicators, their effective use requires careful evaluation, local adaptation, and long-term investment in data infrastructure. Only then can cities like Bratislava move toward a truly inclusive and health-promoting urban environment.

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