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Urban Park Accessibility and Characteristics: Patterns of Spatial Disparity in Zurich

GEO 511 Master's Thesis

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Abstract

Urban parks provide essential health, social and climate-adaptation benefits. Yet, whether access to these spaces is equally distributed across Zurich's socioeconomic and demographic landscape remains unexplored. This thesis examines this question for the City of Zurich by combining a newly compiled dataset of parks with network-based accessibility scores and park characteristics at the level of the city's statistical zones. Park access and characteristics are related to four predictors (median income, share of foreign nationals, share of elderly residents and share of youth) using Spatial Error Models to account for spatial autocorrelation. Furthermore, the thesis conducts other measures of greenspace (forest accessibility and NDVI-derived baseline greenness) to compare to park accessibility.

Results show that park accessibility exhibits no robust association with lower socioeconomic status once spatial autocorrelation is controlled for. Apparent relationships under OLS or bivariate LISA analysis largely reflect Zurich's residential spatial structure rather than an independent effect. Park characteristics, however, tell a more selective story. Median income remains the most consistent predictor of amenity provision. Meanwhile, share of foreign nationals shows no significant association with either accessibility or characteristics. Youth and elderly share display only one association each (vegetation cover and public toilet availability, respectively). Forest accessibility and baseline greenness diverge from park accessibility not only in magnitude but in the direction of their associations with these predictors.

These findings indicate that urban greenspace inequality in Zurich cannot be captured by a single measure or model specification. Urban policy should target amenity-level upgrading of existing parks, particularly in lower-income zones, rather than assuming uniform accessibility gaps. The thesis further contributes a transferable protocol for park dataset construction.

Code availability: The code created and used in this thesis is available on GitHub at MSc_Thesis_SRigoni

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Abbreviations

Table 1: List of abbreviations used in this thesis

Abbreviation	Definition
GSZ	Grün Stadt Zürich (greening department)
LISA	(Bivariate) Local Moran's I Analysis
LM	Lagrange Multiplier
NDVI	Normalized Difference Vegetation Index
OLS	Ordinary Least Square Regression Model
OSM	OpenStreetMap
SEM	Spatial Error Model
TAZ	Tiefbauamt Zürich
UHI	Urban Heat Island
VIF	Variance Inflation Factor

Chapter 1

Introduction

1.1 Motivation

Urban infrastructure shapes the quality of life residents experience daily. Greenspace is among its most visible and essential components. Urban parks in particular provide a variety of functions for surrounding neighborhoods. They are formally designed, publicly available and offer recreation as well as community gathering spaces. Furthermore, they are fulfilling ecological functions by a diversity of vegetation (Q. Chen et al., 2019). Since parks are public goods, they are more regulated and spatially delineated than other types of urban greenspace. This makes their value as well as their accessibility more measurable and therefore policy relevant. Despite their recognized importance for urban quality of life, the term "urban park" lacks a consistent definition across research literature. Studies vary considerably in the conceptualization of urban parks. Some rely on broad, loosely bound characterizations (Bühler et al., 2010), while others apply explicit criteria regarding public accessibility, activity restrictions and minimum size (Kraemer & Kabisch, 2021). This thesis adopts the definition introduced in Section 2.2.1.

This definitional heterogeneity in literature hinders direct comparison across findings. Yet even setting aside definitional challenges, a more fundamental question arises: Who actually benefits from urban parks? While parks are formally open to all residents, access is not spatially uniform. Since parks are fixed in infrastructure, their benefits are geographically tied. Residents living closer to a park benefit more than those living further away (Orstad et al., 2020). As park distribution across a city is rarely random, certain neighborhoods may be systematically better or worse served. This spatial unevenness matters because urban densification does not affect all neighborhoods equally. Research finds that lower-income areas and neighborhoods with higher shares of migrants often face greater densification pressures while simultaneously receiving fewer greenspace investments (Campbell, 1996; Garcia-Lamarca et al., 2021; Wu et al., 2025). This might result in a compounding of lower socioeconomic conditions. Those most exposed to urban heat

and density are also least likely to have a park nearby. Rather than correcting this imbalance, greening investments have been shown to follow economic rather than social need. Therefore, risking the reinforcement of existing socioeconomic disparities.

These social dynamics are compounded by a second, environmental pressure. As climate change progresses, urban areas face new challenges adapting to changing environmental conditions. Urban areas are prone to retaining significantly more heat than surrounding rural areas. Reasons for that are sealed surfaces and tall buildings that absorb more heat. They trap solar energy more efficiently than vegetation or unsealed surfaces would. This heat retention drives rising temperatures that strongly affect quality of life in densely populated areas. At the same time, growing urban populations continue to drive urban densification (Chang et al., 2024). This process intensifies pressures on already constrained urban environments. Together, these dynamics heighten cities' vulnerability to harmful climate processes.

One way to mitigate the urban heat island effect is the selective removal of asphalted surfaces to create space for greenspace within the city. Urban greenspaces are described as "open areas designated for parks and other natural settings" (D. H. Lee et al., 2025, p. 2) in planning but definitions vary across research fields. Greenspaces are also often defined by their functions. A growing body of research indicates that urban greenspaces provide a variety of benefits to urban residents. They help improve physical and mental health as well as reducing heat stress (Groenewegen et al., 2006; Jennings & Bamkole, 2019; Jing et al., 2026; Triguero-Mas et al., 2015). Therefore, greenspaces have become essential tools in urban planning ensuring high quality livability within cities.

Zurich is no exception to these challenges. The Swiss city has launched multiple initiatives aimed at reducing urban heat and expanding greenspace access, including *Stadtklima*[1], *Fachplanung Stadtbäume*[2] and *Programm Stadtgrün*[3]. Yet, Peric et al. (2022) argue that equitable greening remains a major challenge. New parks are often produced through top-down densification processes in which socially vulnerable groups have limited influence. Which means high-quality greening does not necessarily align with socioeconomic need. While Zurich is featured prominently in research on socioeconomic change (Perić et al., 2023; Rérat & Lees, 2011; Rérat et al., 2010), public park access distribution across the socioeconomic landscape remains unexamined. Bühler et al. (2010) investigated park use and social sustainability in Zurich qualitatively. They found that park functionality strongly shapes how spaces are used. Yet, their case study approach did not yield city-wide quantitative results. This thesis addresses this gap by quantifying park accessibility and

[1] `https://www.stadt-zuerich.ch/site/umweltbericht/de/index/stadtklima.html`, accessed on 10.06.2026.

[2] `https://www.stadt-zuerich.ch/de/umwelt-und-energie/natur/stadtbaeume.html`, accessed on 10.06.2026.

[3] `https://www.stadt-zuerich.ch/de/planen-und-bauen/stadtplanung/strategien-und-konzepte/programm-stadtgruen.html`, accessed on 10.06.2026.

characteristics across Zurich's statistical zones. Further it aims to examine their association with lower socioeconomic status. It provides a city-wide, quantitative perspective that qualitative case studies lack.

1.2 Research Problem

Despite growing investment in urban greening, it remains unclear whether public parks in Zurich are equitably distributed. Existing research has addressed park use qualitatively but has not produced city-wide, quantitative evidence. Bühler et al. (2010) investigated park use and social sustainability in Zurich qualitatively. They found that certain groups are systematically underrepresented within the three parks they studied. Elderly residents, for example, appeared significantly less often than other age groups. How park access and park characteristics relate to statistical zone-level socioeconomic and demographic conditions is still unclear. This constitutes a gap with direct policy relevance. Without spatial evidence, the city cannot assess whether its greening initiatives reach those who need them most. Moreover, measuring park inequality requires both a consistent definition of urban parks and systematic account of what parks provide. Two dimensions that existing studies in Zurich have not yet addressed.

1.3 Research Questions

This thesis investigates the relationship between urban parks and the socioeconomic and demographic characteristics of the statistical zones. The goal is to identify potential spatial or social inequities in the distribution of parks. To address this aim, the thesis first establishes a working definition of urban parks. Then it selects open spaces meeting this definition and assign characteristics to the selected park geometries. This selection then functions as the basis of computing park accessibility scores across all statistical zones of the city. The park access score will be compared statistically to the four predictors (median income, share of foreign nationals, share of elderly residents and share of youth). Furthermore, the correlation between socioeconomic/demographic status and park characteristics (vegetation cover, path density, bench density, fountain and public toilet availability) will be examined. The research questions are the following:

RQ1: How can urban parks and their characteristics be defined and measured?

RQ2: How are socioeconomic and demographic characteristics distributed across the statistical zones of the City of Zurich?

RQ3: To what extent are park accessibility and park characteristics across Zurich's statistical zones associated with lower socioeconomic status and demographic vulnerability?

1.4 Research Hypotheses

Research on urban park disparity has shown that lower socioeconomic status is associated with poorer access to urban greenspace. Studies, mostly conducted in North American urban areas, find that lower-income neighborhoods and areas with higher shares of minority residents tend to have poorer access to urban greenspace (Rigolon, 2016; Wolch et al., 2014). Evidence for Zurich specifically is limited. In other cities, however, greening investments seem to follow economic rather than social need. Similar patterns may therefore be expected in the City of Zurich, leading to the following hypotheses:

H1: Correlations between socioeconomic characteristics and park access or characteristics are statistically significant but modest in magnitude, reflecting Zurich's strong planning tradition and comparatively equitable land use governance.

H2: Statistical zones with lower median income and higher shares of foreign nationals have lower park accessibility scores than more affluent zones.

H3: Amenity availability is lower in statistical zones with lower median income, high share of foreign nationals and high share of elderly residents or youth.

1.5 Study Area

1.5.1 City of Zurich

The analysis will be conducted in Zurich, one of the largest and densely populated cities in Switzerland. The city counted 452'421 residents in an area of 91.88 km^2 in the year 2025[4]. The city is formally divided into 12 districts which are further subdivided into 36 neighborhoods and finally 216 statistical zones (Figure 1.1). These zones are created based on population number and build the foundation for comparison in time and space.

Zurich is a compelling case because it is undergoing rapid population growth and intense inner-urban densification. Redevelopment is concentrated in the neighborhoods where socially disadvantaged groups of residents live. According to the *Sozialräumliches Monitoring 2024* report, lower-income households, higher social welfare rates and larger shares of foreign nationals concentrate in northern and western districts (Plüss, 2024). The same areas also contain the city's oldest building stock. That means disadvantaged groups of residents live in areas of high redevelopment pressure. In contrast to this, central and lakeside areas remain socioeconomically advantaged. Furthermore, inner-city neighborhoods show clear signs of change in residents becoming more socioeconomically advantaged. The report also examined forecasts on total population. While all neighbor-

[4]https://www.stadt-zuerich.ch/de/politik-und-verwaltung/statistik-und-daten/daten/bevoelkerung/bestand-und-entwicklung/aktuelle-bevoelkerung-und-entwicklung.html, accessed on 17.04.2026

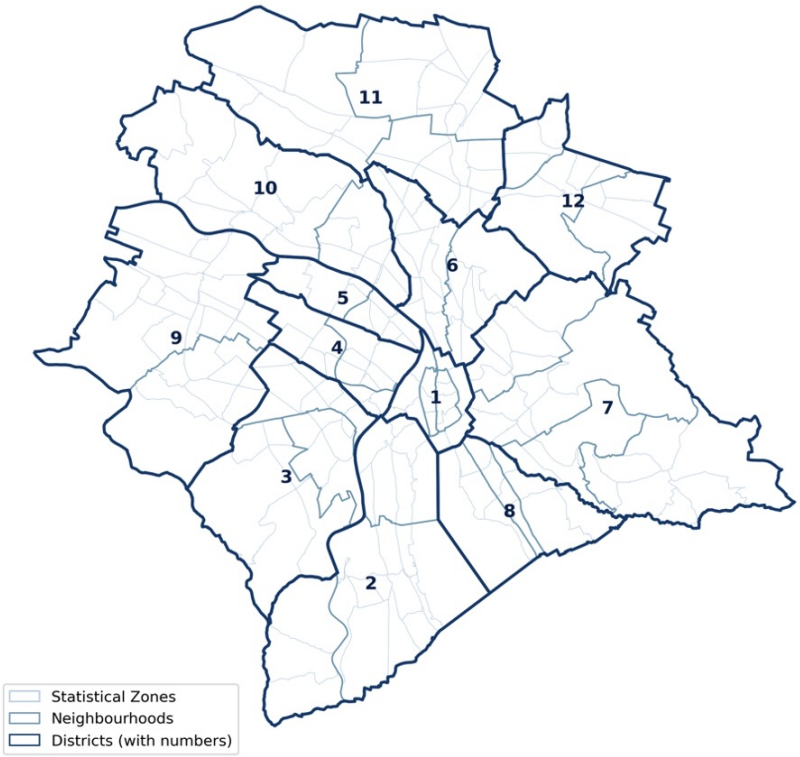


Figure 1.1: Administrative Structure of the City of Zurich. The dark blue lines represent district boundaries and the number is the district numbering. The lighter blue lines are neighborhood boundaries and the lightest blue depict statistical zone borders (the spatial unit used in this thesis).

hoods are expected to experience growth until 2045, peripheral areas show more growth than inner-city areas. This spatial disparity of socioeconomic conditions and developments makes the City of Zurich a particularly relevant context for this thesis.

1.5.2 Greenspace in Zurich

While the City of Zurich contains multiple forests (Figure 1.2), parks are also an essential part of the green landscape of the city. Next to bigger greenspaces like parks, the city's aspiration also lies in other forms of greenspace. Zurich's political landscape allows municipal programs that aim to enhance greenness and well-being within neighborhoods that lack access to greenspace.[5][6] The *Stadtklima* initiatives from 2024 further support such plans. [7]

According to the city, 25 percent (21.76 km^2) of the city is covered by forest (Grün

[5]https://www.stadt-zuerich.ch/de/planen-und-bauen/stadtplanung/strategien-und-konzepte/programm-stadtgruen.html, accessed on 17.04.2026

[6]https://www.stadt-zuerich.ch/de/planen-und-bauen/stadtplanung/strategien-und-konzepte/programm-stadtgruen/programm-1-hitzemindernde-massnahmen-staedtische-gruenflaechen-plaetze-strassenraeume.html, accessed on 17.04.2026

[7]https://www.umverkehr.ch/aktuell/2024-09-23/ueberwaeltigender-abstimmungserfolg-fuer-die-stadtklima-beschluesse, accessed on 20.03.2026

Stadt Zürich, 2019). This makes it a core factor in the greenspace exposure and access for Zurich's residents. In comparison to other types of greenspace identified by the city, the forest is by far the most widespread. Parks for example are measured at 2.5 km^2, cemeteries at 1.29 km^2 and sport grounds at 1.37 km^2. Forest, therefore, makes up a significantly larger portion of the city's surface than any other type of greenspace. Notably, forests in Zurich are not merely wild, unmaintained areas but frequently contain recreational infrastructure. These elements render forests in Zurich functionally comparable to parks in terms of recreational use. This constitutes a key rationale for treating forest accessibility alongside park accessibility in this thesis.

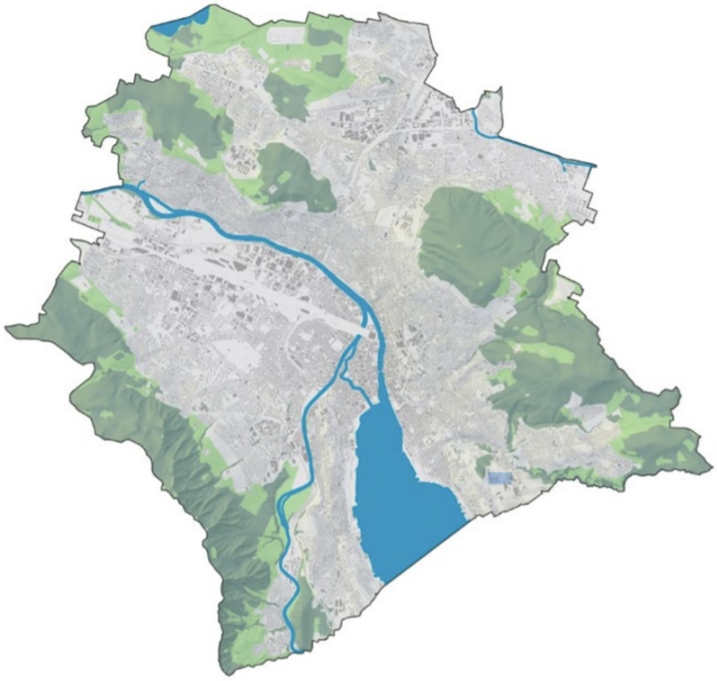


Figure 1.2: Forests (green), settlement area (grey) and water bodies (blue) in the City of Zurich (Source: City of Zurich).

1.6 Thesis Structure

This thesis is structured as follows: Chapter 2 reviews existing literature. It furthermore identifies research gaps this thesis addresses. Chapter 3 presents the data sources and methodology, including park dataset construction, accessibility measurement and the inequality analysis approach. Chapter 4 reports the results of the accessibility and characteristics analyses. Following, Chapter 5 discusses these findings in relation to the research questions and existing literature. Finally, Chapter 6 concludes with a summary of findings, limitations and implications for urban planning as well as future work.

Chapter 2

Related Work

2.1 Urban Greenspace

Urban greenspace shapes both the physical environment and the lived experience of urban residents. As cities grow denser and climate pressures intensify, greenspace draws growing attention for its ecological, social and public health role (Huang & Lin, 2023; Miguez et al., 2025). Yet despite its many functions, urban greenspace remains a contested and poorly bounded concept. Definitions vary across disciplines, spatial scales and institutional contexts. The types of spaces included or excluded carry significant implications for how greenspace is measured, planned and distributed. The section examines how urban greenspace is conceptualized in the literature, before turning to the functions it fulfills in urban environments.

2.1.1 Definition of Urban Greenspace

The concept of urban greenspace lacks a unified definition in the literature. Conceptualizations range from narrow to more expansive understandings. Vague definitions characterize urban greenspace as "open-space areas within cities for parks and recreational purposes" (Miguez et al., 2025, p. 1), focusing primarily on publicly accessible spaces designated for recreation. Broader definitions, by contrast, encompass the full spectrum of urban vegetation. Jabbar et al. (2022), for example, define urban greenspace as "a sum of green paved, open and burial places, sports grounds, private gardens, formal and informal green forests, road verges, derelict land, and horticulture within a city" (p. 4405). This range of definitions reflects the different disciplines that study urban greenspace. The terminology varies just as widely. Literature refers to "open space" (Bengston et al., 2004; Burgess et al., 1988), as well as public and/or urban green space (Barbosa et al., 2007; De Sousa, 2003). D. H. Lee et al. (2025) show that disciplines differ not only in how they define urban greenspace, but also in which functions they attribute to it. This makes measurements harder to compare across studies. As functions and perceptions of urban greenspace

shift, standardized definitions remain elusive. Many researchers therefore study one type of greenspace rather than urban greenspace as a whole. Parks, forests and community gardens are the types most often studied.

The definitional range reflects the multifunctional role greenspace plays in cities. Amid urban densification and rising heat, urban greenspace supports climate regulation (Ren et al., 2025), air quality (Janhäll, 2015) and biodiversity (Miguez et al., 2025). It also serves as a site of social interaction and supports residents' physical and mental well-being (Groenewegen et al., 2006). This diversity of functions is matched by a diversity of greenspace types, which differ in function, size and character.

2.1.2 Functions of Urban Greenspace

Urban greenspace fulfills a diverse range of ecological, social and health-related functions. Collectively, they shape urban livability. In the context of increasing urban heat, the cooling capacity of vegetation is particularly well-documented. Through shading and evapotranspiration, greenspaces reduce ambient temperatures and mitigate urban heat island effects (Manoli et al., 2019; Ren et al., 2025). Beyond thermal regulation, greenspaces contribute to air quality improvement (Janhäll, 2015), storm water management and biodiversity support (Miguez et al., 2025). Alongside these ecological functions, urban greenspaces serve as a setting for physical activity, social interaction and mental restoration (Groenewegen et al., 2006). Access to green areas has been associated with reduced stress, improved psychological well-being and greater opportunities for community cohesion. These are benefits that are not uniformly distributed across urban populations. The multi-functionality makes the equitable distribution of urban greenspace a question of both environmental and social policy. However, despite well-documented benefits, greenspace provision is often constrained by competing land-use priorities and financial limitations (Ren et al., 2025). That means that not all residents benefit equally from these services.

2.2 Urban Parks

Urban parks are among the most commonly studied forms of urban greenspace. They often serve as a primary unit of analysis in inequality-oriented research. Parks represent a clearly delineated, publicly accessible type of green infrastructure that combines ecological, recreational and social functions (Byrne & Wolch, 2009; Jepson et al., 2025; Sister et al., 2010). Unlike more diffuse greenspace forms (e.g. street trees, private gardens) parks constitute a deliberate planning intervention. They are institutionally defined, municipally managed and recorded in official datasets. This makes them particularly amenable to spatial analysis and systematic comparison across urban areas (Fry et al., 2024). Yet this institutional clarity does not translate into uniform access: parks are

not uniformly accessible across urban populations. Their distribution and characteristics vary considerably across neighborhoods, often in ways that reflect broader patterns of socioeconomic inequality (Rigolon, 2016). This combination of institutional clarity and spatial variability makes urban parks a productive lens for greenspace inequality. Therefore, it is also a central object of investigation in this thesis.

2.2.1 Urban Park Definition

Despite a growing body of research on urban parks, a consistent conceptual definition remains elusive. Most studies either neglect it entirely or rely on broad, loosely bounded characterizations. Bühler et al. (2010), for example, define parks as generally accessible spaces that are multifunctional and hold mostly unsealed surfaces and vegetation. The significance of nature within an urban environment is also present in other literature (Feyisa et al., 2014; Kaspar, 2012). A Dutch study confirms this. The most common reason participants gave for visiting parks was to relax and to be in nature (Chiesura, 2004). The role of parks becomes further evident when considering the environmental consequences of their removal (Grimm et al., 2008; Pauleit et al., 2005). As for a park definition, Kraemer and Kabisch (2021) propose a comparatively tight definition. They included only spaces that are (1) owned by the city, (2) have unrestricted (temporal) access for the public (excluding backyards, private spaces and community gardens), (3) have no activity restrictions (excluding for instance cemeteries), (4) contain a substantial part of vegetation and (5) are not forests since they are not as delineated as parks and are generally conceptualized differently than urban parks. These requirements yield a precise picture of an urban park. They provide a useful foundation for the further conceptualization of urban parks.

Another aspect of the definition of urban parks is size. Various studies use size to categorize urban greenspace into different park types. Stanley et al. (2012) define parks as being larger than gardens, but do not give a specific size threshold. The threshold of 0.5 ha (5'000 m^2) as a standard minimum size for an urban park is often used in research. For example, Guo et al. (2019) characterize parks with a size above 0.5 ha as community parks. They are "[m]ainly for residents living in certain residential areas, focusing on children's amusement and the elderly's recreational activities such as rest, sports and recreation" (Guo et al., 2019, p. 104). From a methodological standpoint, greenspaces below this size (e.g. traffic islands, narrow street-side strips) are unlikely to meaningfully host park infrastructure. A minimum area is therefore a prerequisite for these features to be present and measurable. Conceptually, this threshold aligns with international planning standards. The WHO Egorov et al. (2016) recommends that residents have access to greenspaces of at least 0.5 ha within a reasonable walking distance. This minimum size is treated as the necessary extent to provide meaningful recreational and health benefits. Parks below 0.5

ha would therefore fall below the functional minimum considered relevant for public health and well-being. The threshold is further grounded in the broader literature on park size and ecosystem services. Sarı and Bayraktar (2023) demonstrate in a systematic review of 129 studies that park size has an influence on the provision of ecosystem services. They identify ranges of 1 to 5 ha for cultural services (e.g. recreation and physical activity) and 1.4 to 35 ha for supporting services (e.g. biodiversity).

As noted in Section 2.1, urban greenspaces are often defined by their function. While many greenspace types have a distinct purpose (e.g. cemeteries, sport fields), urban parks are recognized as serving the function of leisure and recreation (Nicholls, 2001; Yuan et al., 2025). Cao et al. (2021) frame it even as a social function. Since leisure is a broad term, urban park areas could also be identified by exclusion. By considering all urban greenspace and systematically omitting types whose primary function sets them apart from parks. Cemeteries, for instance, share many physical characteristics with parks. They are open, vegetated and publicly accessible. Yet, their primary function as burial sites places them outside the scope of what constitutes an urban park. This social function of parks is not merely conceptual. It manifests concretely in basic infrastructure such as benches, public toilets and drinking water fountains. These amenities allow visitors to actually spend their leisure time within the park.

Looking for local park definitions, the City of Zurich defines parks as "open-use, predominantly green open space within the settlement area, equipped with recreational infrastructure such as playgrounds, tables, benches, water features and public toilet."[1]

Drawing strongly on Kraemer and Kabisch (2021), this thesis defines urban parks as publicly accessible areas of at least 0.5 ha that do not serve another main function (like e.g. cemeteries or sport fields). Furthermore, urban parks contain a substantially vegetated surface but are distinct from forests, which are another category of greenspace.

2.2.2 Park Benefits

Cities have many reasons to value parks as a use of urban space. According to Cranz and Boland (2004), perceived benefits of parks have evolved over time. In the scope of urban greenspace, public health has been a point of discussion since 1850. However, ecosystem health was only added to the public concern around 1990. Parks, as clearly delineated spaces within cities, contribute a substantial share to the green infrastructure. W.-T. Chen and Ou (2025) show that urban parks provide a range of environmental benefits. They improve air quality, regulate temperature and reduce noise. All while shaping the surroundings and residents. By improving the urban climate in this way, parks enhance

[1]Original: "Nutzungsoffener, vorwiegend grüner Freiraum innerhalb des Siedlungsgebiets mit Erholungsinfrastruktur wie z.B. Spielplätze, Tische, Bänke, Wasserspiele, öffentlichem WC"; https://www.stadt-zuerich.ch/de/planen-und-bauen/stadtplanung/strategien-und-konzepte/gruenbuch/glossar-gruen-stadt-zuerich.html#o-r, accessed on 03.03.2026.

the overall livability of the city. Meanwhile, they enable greenspace and urban density to exist side by side.

Beyond their environmental benefits, parks have also been recognized as parts of urban community development. A substantial body of research documents the social benefits parks bring to a neighborhood (Burgess et al., 1988; Enssle & Kabisch, 2020; F. Zhang & Qian, 2024). Parks create opportunities for social contact, strengthen community ties and foster a communal spirit among residents (Peters et al., 2010). Parks also reinforce residents' sense of place and belonging (Williams & Vaske, 2003).

The third dimension of park benefits is the mental and physical health implications. A large body of literature perceives urban parks mainly as areas where physical activity is possible and reinforced (Bedimo-Rung et al., 2005; Petrunoff et al., 2021; Poppe et al., 2022). Furthermore, literature shows that mental health can strongly benefit from well-maintained and safe urban parks near residents (Orstad et al., 2020). According to Wood et al. (2017), the nature aspect is thereby crucial for mental health improvements. They argue that urban greenspaces have a greater effect on mental health if the focus lies on vegetation cover.

2.2.3 Urban Park Characteristics

Park Characteristics and Quality

High-quality greenspace contributes to the well-being of nearby residents and visitors (Jiang & Huang, 2022). Meanwhile, low-quality greenspace can reduce attractiveness, suppress potential benefits and even harm well-being (Brindley et al., 2019). To date, however, there is no unified method for assessing greenspace quality (Wu et al., 2025). Many studies operationalize quality by examining specific park characteristics, such as condition, aesthetic and safety (McCormack et al., 2010), or features such as seating, picnic tables and public toilets (W. Chen et al., 2024). Most of this literature aggregates these characteristics into composite scores (e.g. Kraemer & Kabisch, 2021; Liu et al., 2026). Although, some authors treat each characteristic as an individual unit of analysis (Kirsteina et al., 2025). The following review serves two purposes. First, identifying which characteristics are consistently considered relevant. And second, showing why aggregating them into a composite score is methodologically and conceptually problematic.

The measurement of park quality has evolved significantly over the past two decades. It moved from purely spatial assessment (size and location) towards more comprehensive, attribute-based approaches. In a systematic review of 18 protocols for evaluating park quality, S. Chen et al. (2020) find broad methodological conformity. The predominant approach is direct on-site observation, while a growing share of research employs remote sensing technologies such as *Geographical Information Systems (GIS)* and satellite data. Landscape and aesthetic features, facilities and amenities, as well as maintenance conditions

emerge as the most consistently included characteristics. They provide a useful empirical anchor for defining which characteristics matter most to an objective framework. This body of work, however, also exposes limitations relevant to inequality research. Most protocols are developed from a physical activity perspective, reflecting health and leisure research. This excludes perspectives of relaxation, social interaction and education. S. Chen et al. (2020) further note that no protocol was specifically designed for low-income or elderly populations.

More recent work addresses these limitations, specifically the over-reliance on physical activity and the neglect of subjective user dimensions. Liu et al. (2026) exemplify this shift, combining remote sensing-derived landscape metrics (including blue and green coverage rate, landscape shape complexity, heterogeneity and diversity) with social media-based visit and sentiment data. With this they construct a composite quality index. Yet even this more comprehensive approach reveals a fundamental tension. Objective characteristics and subjective user experience often diverge, especially in peripheral urban locations. For inequality-oriented research, this mismatch is particularly consequential. Measuring park quality through physical attributes alone (as most established protocols do) may systematically underestimate the challenges faced by residents in lower-income, peripheral zones.

Crawford et al. (2008) provide further empirical evidence for this socioeconomic dimension. Public open spaces in neighborhoods with the highest socioeconomic status contained more amenities, such as fountains, paths and shade-providing trees. This higher number of features was associated with greater physical activity, especially among children. Park quality thus appears shaped not only by the presence but also by the quantity of its characteristics. A park with few amenities is unlikely to be used the same way as one offering many amenities.

This body of literature shows a recurring set of measurable characteristics that are operationalized into park quality scores. Translating them into a single composite score, however, raises issues of weighting (Greco et al., 2019). Assigned weights often misrepresent the real-world importance of score components, while equal weighting distorts results just as much. It is unlikely that all characteristics influence park quality equally. A value-neutral assessment of individual park characteristics can therefore offer further insight into park provision across neighborhoods.

Selection of Park Characteristics

Urban park characteristics have a significant impact on park visitation and the benefits derived from parks (Bedimo-Rung et al., 2005; Liu et al., 2026). It makes the selection of which characteristics to include essential to the assessment of park quality.

Existing typologies illustrate the breadth of this selection. Cranz and Boland (2004) characterizes park types along dimensions such as social goal, activities, size, relation to the

city and physical elements. Nguyen et al. (2021) propose an even broader set of categories. They encompass environment and land cover types, natural features, infrastructure and amenities, size, shape, pattern and connectivity, as well as safety.

This selection, however, is itself not free of bias. K. Lee et al. (2024) identify several limitations in existing park quality assessments. Most notably the insufficient consideration of marginalized groups' experiences and an over-representation of physical activity and health outcomes. This focus has resulted in frameworks that systematically overlook the needs of socially vulnerable residents and reduce park quality to a narrow set of measurable physical characteristics. Meanwhile, neglecting the broader social and cultural dimensions that shape how different communities experience and benefit from urban parks.

Building on these findings, this thesis attempts to broaden the selection of park characteristics beyond a purely activity-based focus. Section 3.4 therefore presents characteristics that account for the needs of park visitors from marginalized communities (i.e elderly and infant/juvenile, low-income and non-citizen residents).

2.3 Urban Climate Challenges

While cities promote economic growth and social transformation, they are also highly vulnerable to the impacts of climate change (D. Wang et al., 2025). As climate change increasingly affects urban areas, ensuring equal access to resources has become a central concern in urban development. The United Nations Sustainable Development Goal 11 (SDG11) highlights the crucial role of cities in fostering human well-being and enhancing resilience to climate-related risks (Rising et al., 2022). This section reviews strands of literature: urban densification, the contribution of dense built environments to heat accumulation and the uneven distribution of cooling resources such as urban greenspace.

2.3.1 Urban Densification

Urban areas are expanding worldwide. While the United Nations report that about 55 percent of the world's population live in cities (United Nations, 2019), the figure is expected to rise to 68 percent by the year 2050 (Sun et al., 2020). This growth transforms urban landscapes through two processes: densification or expansion (Forman, 2014). Scholars disagree about the extent to which densification represents a universally applicable or desirable response to urban growth. Outcomes vary considerably depending on local context and existing urban form (Neuman, 2005).

Densification is widely promoted as a strategy to accommodate population growth while limiting urban sprawl, protecting non-urban areas such as agricultural land and natural ecosystems (Amponsah et al., 2022; He et al., 2023). It is broadly defined as a process whereby the number of households increases within existing urban boundaries (Broitman &

Koomen, 2015; Forman, 2014). Typically, it occurs through the replacement of low-density structures, redevelopment or the construction of high-rise buildings. Critics, however, argue that densification strategies frequently overlook the distributional consequences of growth. This also includes rising housing costs and the displacement of lower-income residents (Bramley & Power, 2009; Debrunner et al., 2024).

Beyond these social concerns, the broader sustainability case for densification has also been questioned. Densification is often associated with the concept of the compact city. It aims to increase efficiency in land use, infrastructure and energy consumption by concentrating development within existing urban boundaries (Artmann et al., 2019). While density is linked to reduced travel distances, the empirical evidence for these claims remains inconclusive. Neuman (2005) concludes that the relationship between compactness and sustainability is at best weakly correlated. In some cases even negative, with travel behavior appearing more strongly determined by fuel prices and income than by urban form alone. Burton (2000) further demonstrates that social inequality outcomes show only a limited relationship with compactness. They even are negatively affected by it in many cases.

Central to this debate is what Neuman (2005) terms the compact city paradox. The observation that sustainability and livability pull in opposing directions. A city optimized for sustainability may simultaneously undermine the qualities that make it livable. Access to greenspace, quiet streets or a perceived sense of safety are just a few of these qualities. Conversely, the low-density suburban form that many residents actively prefer tends to generate higher resource consumption and infrastructure costs. Neuman (2005) argues that this paradox cannot be resolved within existing modes of thinking about urban form, as both compact and dispersed development continue in parallel, driven by competing preferences and market forces.

As Wolch et al. (2014) point out, this tension is particularly visible in the case of urban greenspace. While densification is intended to protect natural land at the urban periphery, it can simultaneously increase environmental and social pressures within the city itself. Also including reduced access to parks and greenery for urban residents.

Environmental and Social Implications of Densification

While urban densification is widely promoted as a sustainable planning strategy (Bibri et al., 2020), it is also associated with a range of environmental and social implications. From an environmental standpoint, increasing building density typically leads to higher proportion of sealed surfaces and reduction of vegetated areas. This transformation alters a city's microclimate by limiting natural cooling processes such as evapotranspiration and shading, while simultaneously increasing heat storage in built materials. As a result, densification can intensify urban heat accumulation (X. Chen et al., 2023).

In addition, densification puts pressure on limited urban land. As development is con-

centrated within existing boundaries, land becomes a scarcity. It must be allocated among competing uses, including housing, infrastructure and open or green spaces (Artmann et al., 2019; Daniels et al., 2018). This competition often leads to loss, fragmentation or reduction of urban greenspace. Meanwhile, it also complicates efforts to integrate new green infrastructure into dense urban environments. Furthermore, planning strategies may seek to incorporate greenspace as part of densification processes.

Beyond environmental impacts, densification is closely connected to social transformations. Redevelopment processes and the construction of higher-density housing are often associated with rising property values and rent levels (Debrunner et al., 2024). This dynamic can add to the displacement of existing residents and changes in the social composition of neighborhoods (Davidson & Lees, 2005). Critically, these dynamics are not evenly distributed. Economically and socially vulnerable groups are disproportionately affected by rising housing costs and reduced availability (A. Li et al., 2025). Bramley and Power (2009) caution, however, that once demographic and socioeconomic characteristics of residents are controlled for, the direct effect of urban form on social sustainability outcomes is substantially reduced. This suggests that many apparent consequences of densification may be attributable to population composition rather than to density itself.

Overall, densification reshapes not only the physical structure of a city but also the distribution of environmental and social resources. These interacting pressures on urban climate, land availability, housing market and social inequality underscore the need to critically assess densification strategies with respect to long-term urban sustainability. Of particular concern is the fate of urban greenspace, which sits at the intersection of these environmental and social dynamics.

Densification in Swiss Cities

The Swiss context provides a particularly instructive case for examining the social tensions in urban densification processes. Since the revision of the Spatial Planning Act in 2014, federal policy has explicitly promoted inward development. It is supposed to protect agricultural land and limiting urban sprawl (Debrunner et al., 2024). As a result, Swiss cities have increasingly pursued densification through the redevelopment of existing residential neighborhoods.

These pressures are compounded by the structural characteristics of the Swiss housing market. With one of the lowest home-ownership rates in Europe, a large share of the urban population depends on the rental market (Rérat, 2012). This making residents particularly vulnerable to the displacement dynamics that often accompany redevelopment. As Debrunner et al. (2024) document, tenants are frequently pressured to vacate their homes during renovation. Afterwards, they are often unable to return once construction is complete, as rents increase substantially. This displacement risk is further reinforced by an asymmetry in legal protections. Swiss tenancy law affords renters considerably fewer

rights than homeowners in the context of redevelopment (Debrunner et al., 2024).

At the municipal level, densification decisions rest largely with local authorities. And their planning priorities do not always align with the interests of existing residents. In Zurich, the scarcity of undeveloped land has intensified competition over remaining open and green spaces. New construction must be accommodated within an already densely built environment (Gerber & Debrunner, 2022). This spatial constraint places urban greenspace under particular pressure. A dynamic that is examined in greater detail in the following sections.

2.3.2 Urban Heat Island Effect

Urban Heat Islands (UHI), a phenomenon of cities displaying significantly higher temperatures compared to their rural surroundings, pose a significant threat to human health (Oke, 1973; Romero Rodríguez et al., 2020). In Switzerland, urbanized lowland cities such as Zurich, Geneva and Basel exhibit substantially higher heat exposure than mountainous or rural municipalities, with topography acting as a key moderating factor (Chang et al., 2025). A substantial body of research links heat stress to serious health consequences (Basu & Malig, 2011; Epstein & Moran, 2006; Kovats & Hajat, 2008; Zendeli et al., 2026). Elevated ambient temperature has measurable mortality effects. Excess mortality risk rises by around 4 percent per 5.6 °C increase in apparent temperature. This affects particularly children, adults over the age of 50 and those with preexisting conditions (Basu & Malig, 2011). As a consequence of this substantial link, many studies investigate heat detection and mitigation in urban planning (Fünfgeld et al., 2026; Pfautsch et al., 2023; Y. Wang & Akbari, 2016). The large amount of sealed surfaces in cities creates conditions in which solar radiation is absorbed and retained, leading to increased temperatures. Furthermore, the low vegetation cover compared to rural areas intensifies this heating process (Manoli et al., 2019). Vegetation and permeable surfaces contribute to cooling through evaporation and water storage, thereby reducing surrounding temperatures. In addition, anthropogenic heat emissions (e.g. from traffic) further contribute to the urban heat island effect.

2.3.3 Social Inequalities in Heat Exposure

The impacts of urban heat are not distributed equally across urban populations. Research shows that groups with lower socioeconomic status face disproportionately higher heat exposure. This creates a compounding burden of environmental and social inequality (Lin & Zeng, 2026). However, the nature of this inequality varies with the scale of analysis. In Switzerland, municipalities with higher shares of non-EU foreign residents and social assistance recipients tend to experience elevated heat exposure (Chang et al., 2025). Many of these associations are partly mediated by elevation and urban form. At the national scale, Osberghaus and Abeling (2022) find no significant difference in heat hazard or exposure

between income groups in Germany. Instead, low-income households are distinguished by greater heat sensitivity and lower adaptive capacity. This includes reduced access to air conditioning and fewer economic resources to implement protective measures. Furthermore, a US study shows that outdoor workers face prolonged heat exposure with limited ability to seek relief (Shkembi et al., 2025). And they are disproportionately represented by lower-income and minority populations. Housing quality also plays a significant role. Poorly insulated or overcrowded dwellings retain heat more effectively, further elevating indoor temperatures during heat events. Therefore, the unequal distribution of heat risk is shaped by both physical and socioeconomic factors that are deeply intertwined.

At the neighborhood level, land surface temperatures are strongly correlated with historical patterns of urban development and investment. Areas characterized by high proportions of sealed surfaces, limited tree canopy cover and dense built structures tend to exhibit significantly higher temperatures (Manoli et al., 2019). These conditions then disproportionately concentrate in lower-income and minority neighborhoods (Chang et al., 2025).

Certain population groups are particularly at risk. Elderly individuals, young children and people with pre-existing health conditions exhibit heightened physiological vulnerability to heat stress (Kovats & Hajat, 2008). In the Swiss context, areas with the highest shares of residents ages 80+ tend to experience above-average heat exposure (Chang et al., 2025). This connection underscores the intersection of physiological vulnerability and environmental risk. When vulnerabilities overlap with lower socioeconomic conditions and physical heat exposure, the resulting risk is substantially amplified. Studies in European and North American cities have demonstrated that mortality and hospitalization rates during heat events are significantly elevated in low-income populations (Basu & Malig, 2011; Orlando et al., 2021).

The spatial concentration of heat vulnerability within specific urban neighborhoods calls for targeted planning responses. Urban green infrastructure (including parks, street trees and green roofs) has been identified as a key instrument for mitigating localized heat exposure (Ren et al., 2025). Yet greening interventions can themselves trigger gentrification, displacing the very population they were meant to benefit. A dynamic referred to as "Green Gentrification" (Anguelovski et al., 2022). Addressing heat inequality therefore requires not only environmental interventions but accompanying social and housing policies that ensure equal access to cooling resources.

2.4 Urban Greenspace Inequality

As with heat exposure, the benefits of urban greenspace are not distributed equally across urban resident groups. With all the gains urban greenspace provides for a city's residents, this raises the question of distributional fairness: who benefits from these advantages

and who does not. Greenspace inequality is therefore a well-studied field, drawing on urban planning, transportation, public health, ecology and environmental justice. These fields converge when considering the ongoing changes in urban structures caused by urban densification (Section 2.3.1) and climate challenges (Section 2.3). Looking at an extensive body of literature, it becomes clear that these challenges cities face reproduce inequalities among city residents. Wu et al. (2025) identify defining urban greenspace as a prerequisite that many studies neglect, making it hard to compare greenspace mapping for further disparity analysis. Furthermore, they note that while new technologies have improved the capturing of greenspaces, the missing definition still leads to uncertainties which make comparison harder (see also Section 2.2.1). This discussion is structured around two aspects: how greenspace access is distributed (Section 2.4.1) and how inequality itself is operationalized through socioeconomic and demographic indicators (Section 2.4.2). That also includes how the empirical evidence on access, characteristics and disparity diverges.

2.4.1 Urban Greenspace Accessibility

Accessibility to urban greenspace is an essential aspect within the greenspace inequality discussion. Measuring the interaction between residents and greenspace in the form of greenspace accessibility can be approached in two distinct ways, according to Wu et al. (2025): person-based and place-based. While the person-based approach investigates the ability of people to reach places, the place-based perspective looks at how a location is reachable. Often used in this context are cumulative-opportunity measures (*isochronic indices*) which assess travel time or distance around a reference point. They then measure accessibility as the number (or share) of opportunities falling within this boundary (Sherman et al., 1974).

Beyond cumulative-opportunity measures, a second family of accessibility measures relies on gravity-based, or distance-decay, models. They weight opportunities by their proximity rather than applying a fixed cutoff. Thereby, they capture accessibility as a continuous rather than a binary function of distance (P. Chen et al., 2024; Hansen, 1959). Both approaches have been applied widely to study access to urban greenspace. Parks have received by far the most attention among the various greenspace typologies.

Both cumulative-opportunity and gravity-based measures remain place-based by construction and therefore only approximate what residents actually experience as accessible. El Murr et al. (2023) directly compare calculated, place-based accessibility to parks against residents' self-reported accessibility in Montreal. They find that the two frequently diverge. The number of accessible parks was even negatively associated with self-reported accessibility. The composite measure incorporating park attributes, such as play facilities, water features and safety, corresponded considerably more closely to residents' perceptions. This finding suggests that place-based proximity measures relying solely on park counts

or area may not adequately capture what actually renders a greenspace accessible in a meaningful sense. A limitation that needs to be kept in mind when working with park accessibility and its disparity.

A similar pattern emerges specifically for Zurich. Dopico et al. (2025) examine determinants of greenspace visits. They find that park size and the presence of water bodies are the strongest predictors of visitor numbers. Meanwhile, individual visit frequency is additionally shaped by residential greenness, proximity to parks and perceived free time. This reinforces the notion that formal, place-based accessibility measures alone do not fully capture what drives residents' actual use of greenness.

Urban greenspace encompasses a range of typologies, including forest and other vegetated open spaces. Yet the social inequality literature has focused extensively on parks. This is likely owed to their central role in everyday urban recreation. Park accessibility is consequently among the most studied dimensions within the greenspace inequality literature. Drawing on a growing body of international evidence, groups with lower socioeconomic status tend to have poorer access to urban parks (Boone et al., 2009; Byrne & Wolch, 2009; Rigolon, 2016; Rigolon et al., 2018).

2.4.2 Inequality Discussion

Research on greenspace inequality mostly examines how access varies across social groups. Studied factors include low economic status and racial minority status (Tian et al., 2021), age (R. Wang et al., 2022), gender (Runkle et al., 2022) or marital status (Ribeiro et al., 2021). Household composition and life stage also shape residential location choices more broadly. In the Swiss context, Pagani et al. (2021) show that residential preferences and the housing priorities vary systematically with life stage and household type. That dynamic then contributes to the sociodemographic sorting of populations across a city's neighborhoods.

Evidence on whether this sorting translates into unequal park access is mixed. Some studies find no correlation between marginalized neighborhoods and disparities in access to public services such as urban parks (Mladenka & Hill, 1977). A large body of research disagrees. It documents spatial patterns in which areas of low socioeconomic status also have poor park access. A study across multiple US cities, for instance, finds a disproportionate lack of park access in areas predominantly inhabited by ethnic minorities (Talen, 1997).

Hughey et al. (2016) extend this evidence from availability to quality. While no correlation between number of parks and neighborhood disparity was found, lower status districts show higher crime rates within parks, reducing their quality to residents. Within wealthy neighborhoods, they further find that a higher share of minority residents is associated with fewer park amenities. This underscores that examining park characteristics

in detail is crucial for understanding inequality in greenspace provision. Ibes (2015) responds to this need with a multi-dimensional classification of parks based on their physical, land cover and built features. This classification correlates strongly with specific social neighborhood characteristics. It allows her to both identify disparity concerns and pinpoint priority areas for park improvement.

R. Zhang et al. (2021) discovered that lower socioeconomic status groups of residents often have limited access to greenspaces. Furthermore, a study conducted in Shanghai finds that groups with lower social status benefit more from urban greenspace policies (Xiao et al., 2017). This suggests that policy design may offer a lever for addressing existing disparities.

Much of the evidence on park access and quality, however, is drawn almost entirely from US cities. This raises questions about how well it generalizes to other geographic and institutional contexts. Rigolon et al. (2021) address a related question directly in a systematic review of 90 studies. They examine whether groups with lower socioeconomic status derive greater health benefits from greenspace than privileged groups. And find that greenspace, particularly public parks, shows stronger protective health effects for low-socioeconomic-status populations than for high-status populations. This result runs counter to their own hypothesis, since the comparatively lower park quality documented in lower socioeconomic status US neighborhoods would be expected to weaken this relationship. Critically, this protective effect was significantly more pronounced in European studies than in North American ones. The authors attribute this to smaller disparities in park quality and stronger public welfare provision in Europe relative to the US. The continental contrast suggests that findings on park inequality drawn primarily from the US context may not transfer directly to a Western European setting.

2.5 Research Gaps

While the reviewed literature demonstrates substantial progress in understanding urban greenspace, its accessibility and the inequality discussion around it, several gaps remain unaddressed. Specifically, four gaps have been identified:

2.5.1 Urban Park Definition

Despite the growing volume of research on urban parks, a consistent conceptual definition remains largely absent from the literature. As shown in Section 2.2.1, most studies either neglect an explicit definition entirely or rely on broad, loosely bounded characterizations that vary considerably across disciplines and institutional contexts (D. H. Lee et al., 2025). This lack of definitional consistency directly undermines the comparability of greenspace mapping and inequality analyses that build on it (Wu et al., 2025). Kraemer and Kabisch

(2021) constitute a notable exception, offering explicit and replicable criteria for delineating urban parks. A further consideration specific to this thesis is that the park definition must ultimately be operationalized as a set of spatial attributes suitable for GIS-based filtering. And not as a purely conceptual or qualitative characterization. This thesis addresses this gap by adopting and adapting the criteria proposed by Kraemer and Kabisch (2021) to the Zurich context. Thereby providing a transparent and reproducible park definition that underlies all subsequent analyses (Section 3.2).

2.5.2 Analysis of Park Characteristics in Inequality Discussion

While park characteristics are well established as a determinant of park visitation (Bedimo-Rung et al., 2005; Liu et al., 2026), their relationship to lower socioeconomic status and demographic vulnerability remains insufficiently examined. Existing frameworks for selecting and assessing park characteristics developed predominantly from a physical activity perspective. No framework has been specifically designed for lower-income or elderly populations (S. Chen et al., 2020). K. Lee et al. (2024) similarly identify an insufficient consideration of marginalized groups' experiences. The existing selection criteria result in a narrow set of physically measurable characteristics that neglect the broader social and cultural dimensions. Therefore, shaping how different communities use and benefit from parks. Where characteristics are related to inequality at all, they are typically aggregated into a single composite score. This practice obscures which individual characteristics are actually associated with lower socioeconomic position (Greco et al., 2019). This tension between subjective and objective measurement is also evident closer to the context of this thesis. As introduced in Section 2.4.1, Dopico et al. (2025) assess park quality primarily through subjective perception and behavioral measures rather than through parks' objective physical characteristics. Their study offers valuable insight into what draws residents to greenspace, but leaves the physical characteristics themselves unexamined. This thesis addresses this gap by analyzing five park characteristics (vegetation, path, bench, fountain and public toilet provision) individually rather than as a composite index. Furthermore, each characteristic is related to socioeconomic and demographic predictors (Section 3.4).

2.5.3 Inequality of Park Access in Zurich

The empirical evidence on greenspace inequality is overwhelmingly drawn from US cities, raising concern about geographic and institutional contexts. Rigolon et al. (2021) provide direct evidence for this concern. In their systematic review, the authors examined the protective health effects of greenspace access for groups of lower socioeconomic status. These effects were significantly more pronounced in European studies than in North American ones. The authors attribute this pattern to smaller disparities in park quality

and stronger public welfare provision in Europe. This suggests that findings on park inequality established primarily within the US context may not transfer directly to a Western European setting. To date, no study systematically examined park accessibility and characteristics in relation to socioeconomic/demographic status in a Swiss city. This thesis addresses this gap by conducting an analysis for the City of Zurich. Thereby extending the greenspace inequality literature to a European, welfare-state context that remains underrepresented (Chapter 4).

2.5.4 Divergence Across Greenspace Measures

Existing inequality research predominantly examines a single type of greenspace. Other types such as forests or general vegetation cover remain comparatively understudied within the same analytical framework. As a result, little is known about whether different greenspace typologies exhibit similar or divergent spatial patterns. Also whether inequality relationships identified for one typology extend to others. This omission is consequential, as types of urban greenspace can differ substantially in their spatial distribution, institutional management and accessibility. This could potentially produce conflicting inequality implications depending on which typology is analyzed. This thesis approaches this gap by jointly examining park accessibility, forest accessibility and general vegetation cover (baseline greenness) within a single inequality framework. This allows for a direct comparison of the spatial and social patterns associated with each type of greenspace (Section 5.2).

Chapter 3

Data and Methodology

This chapter presents the data and methods underlying the three core analyses of this thesis: park accessibility, park characteristics and their socioeconomic and demographic correlates. Based on the park definition established in Section 2.2.1, this chapter first describes how a validated park dataset was constructed from multiple urban greenspace sources. It then introduces the datasets used to characterize parks, measure pedestrian accessibility and capture socioeconomic and demographic context at the statistical zone level. The statistical zones of the City of Zurich serve as the spatial framework throughout and are introduced in Section 3.1. Section 3.2 then details the construction of the park dataset. The subsequent sections describe the accessibility scoring approach (Section 3.3) and the characterization of parks (Section 3.4). Additionally to park accessibility, Section 3.5 and Section 3.6 show two greenspace measures for comparison and validation of the park accessibility. After that, the socioeconomic and demographic predictors are introduced (Section 3.7) which is followed by the inequality analysis framework (Section 3.8).

An overview of all datasets used in this thesis is provided in Table 3.1. For further information on resolution, access conditions and link on datasets, see Table A.1 in Section A.1. All data processing, spatial analysis and visualization for this thesis were conducted in Python (see Section A.2 for an overview of the main packages used).

Table 3.1: Overview of datasets used in this thesis.

Dataset	Description
Age Composition	Data on age composition of all statistical zones
Baumkataster	Tree register for tree canopy cover
Brunnen	Fountains within city borders
Foreign nationals[a]	Share of foreign nationals
Fuss- und Velowegnetz	Primary pedestrian/cycling network
Grünflächen	Greenspaces maintained by the city
Median Income[a]	Median income, married and non-married rates
OpenStreetMap Datasets	Used for park selection, park characteristics
Sitzbankkataster	Bench register within city borders
Statistical zones	Spatial unit of analysis
STATPOP[a]	Residential building locations
SWISSIMAGE RS	NDVI-based vegetation cover
swissTLM3D	Federal land cover layers
Waldareal	Forest areas in the Canton of Zurich
ZüriWC	Public toilets within city borders

[a] Requested directly from the data provider; not publicly available.

3.1 Study Design

This thesis adopts a cross-sectional, observational study design to examine the distribution of urban parks access and characteristics across the City of Zurich's statistical zones (Figure 3.1). The analysis proceeds in three interconnected steps which correspond to the three research questions. After the park selection, pedestrian accessibility to parks is measured using a network-based approach and aggregated by zone. Then, parks are individually characterized by the following park elements: vegetation cover, path density and amenities (benches, fountains and public toilets). Furthermore, characteristics are individually computed into a characteristic provision score. Following this, both accessibility and characterization outcomes are related to socioeconomic and demographic characteristics of statistical zones through statistical analysis. This allows for an assessment of distributional inequality. All three dimensions are analyzed at the level of statistical zones. Of the 216 zones, four lake zones and the Paradeplatz zone (which lacks income data in 2022) are excluded. As a result, an analytical sample of 211 zones emerges. It serves as the primary unit of observation throughout this thesis.

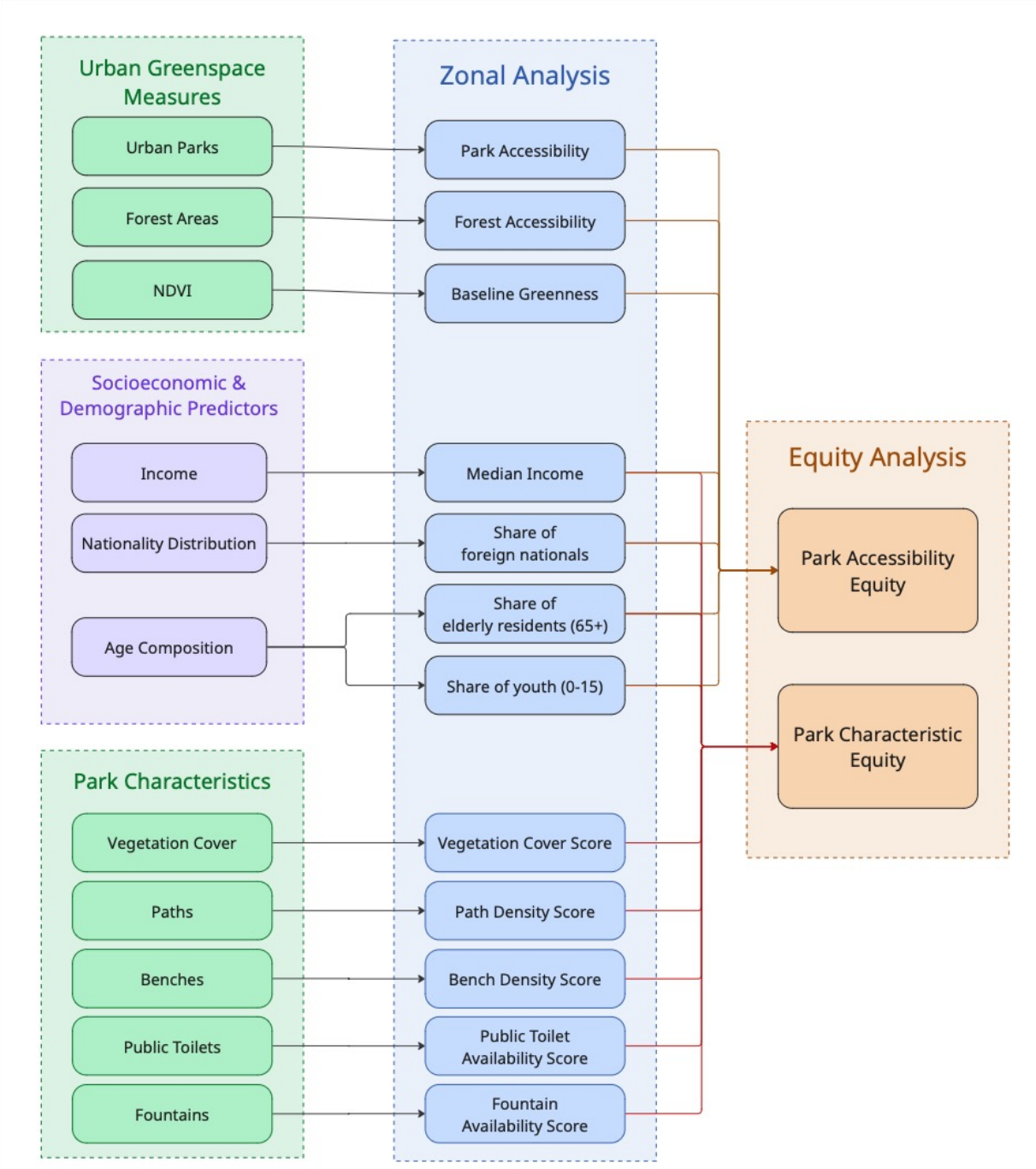


Figure 3.1: Overview of general workflow of the thesis.

The statistical zones of the City of Zurich serve as the spatial basis for this thesis. All values computed for park accessibility as well as socioeconomic/demographic variables were displayed and analyzed on statistical zone level. For this, the city's dataset *Statistische Zonen* (City of Zurich, 2026c) was used. Statistical zones were preferred over the coarser neighborhood level for two reasons. First, with the original 216 zones compared to 34 neighborhoods, statistical zones provide a finer spatial resolution that better captures variation within neighborhoods for both park access as well as socioeconomic and demographic

conditions. Socioeconomic gradients within a single neighborhood can be substantial in a city like Zurich, where redevelopment processes are concentrated and spatially uneven (**pluss_stadt_2024**). Second, all socioeconomic and demographic variables (median income, share of foreign nationals, share of elderly residents and share of youth) are available at the statistical zone level from the city's statistical office upon request, making this unit the natural choice for integrating the analytical dimensions of this thesis.

3.2 Park Dataset Construction

The first step of this thesis was the construction of a park dataset. It contains all open spaces defined as urban parks in the City of Zurich. Figure 3.2 shows the overall workflow of this procedure:

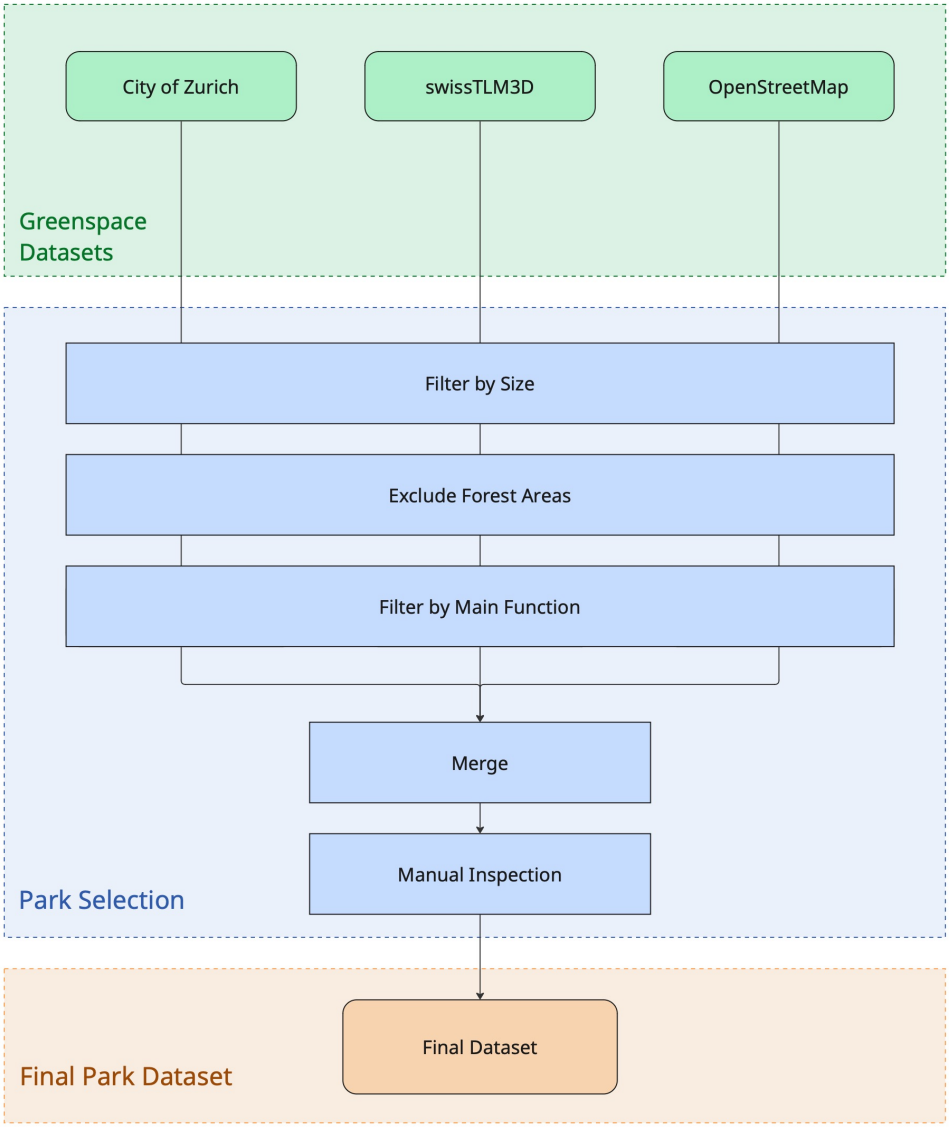


Figure 3.2: Overview of the construction of the park dataset.

3.2.1 Data Sources

As this approach required a broad scope on greenspace data, multiple data sources were consulted. As the following sections will elaborate in more detail, the city's dataset *Grünflächen* was considered as the primary source. It is a formally collected and maintained dataset which is captured in high precision. Additionally, the federal dataset *swissTLM3D* and data from OpenStreetMap (OSM) were consulted to fill potential gaps in the city's dataset.

Municipal Greenspace Dataset

The first dataset to consider was the greenspace dataset named *Grünflächen* (City of Zurich, 2026c), provided by the City of Zurich's greening department (*Grün Stadt Zürich*, GSZ). It contains all publicly accessible greenspaces in the city that are maintained by the department. The data is stored as polygon geometries in LV95 (EPSG:2056) covering the entire urban territory. This vector dataset includes polygons that are categorized by multiple attributes (management unit, product type and cadastral recording unit) (Table 3.2). The dataset is openly available via the City of Zurich's open geodata portal and is updated on a weekly basis (data accessed in November 2025). Table 3.2 displays the attributes of the dataset with a short description and example values. In total the dataset contains 60'145 features of which 8'673 are categorized as parks (*Parkanlagen*). As each park is split up into maintaining units (e.g. meadow, flower bed, gravel path), this number is still rather high and does not yet represent the number of parks in Zurich.

Table 3.2: List of relevant attributes of municipal greenspace dataset (*Grünflächen*) with description and example values (Source: City of Zurich).

Attribute	Description	Example values
'Pflegeareal'	Name of maintained area	`Sportzentrum Hardhof`, `Grosse Kirche Fluntern`, `Wahlenpark`
'Produkt'	Type of maintained area (numbered)	`610 Parkanlagen`, `620 Friedhöfe`
'Erfassungseinheit'	Type of maintained area (additional to 'Produkt'; numbered)	`611 Parkanlagen`, `624 Friedhofanlagen`
'Pflegeeinheit'	Vegetation type within maintained area (numbered)	`2433 Mauer`, `2433 Formhecke`, `2433 Blumenwiese`
'Vegetationstyp'	Vegetation type	`Mauer`, `Formhecke`, `Blumenwiese`

Figure 3.3 shows how this dataset is compiled. The displayed park (Josefwiese) also

shows how this dataset only contains outside spaces. Buildings within a park would not be counted as park area (see white spots surrounded by colored areas in Figure 3.3). In the example of Josefwiese, one of the two white spots represents a building of a small restaurant. Since this dataset is managed by the greening department, inside spaces are deemed irrelevant. Assumably, that this data is mainly used by employees of the greening department that work in the field and need to be able to characterize distinct areas hands-on. Consequently, elements outside the maintenance scope such as informal pathways or privately managed amenities are not represented in this dataset. Nevertheless, the high measure of detail is an advantage of this dataset. In later use of investigating park characteristics, this level of detail will be useful.

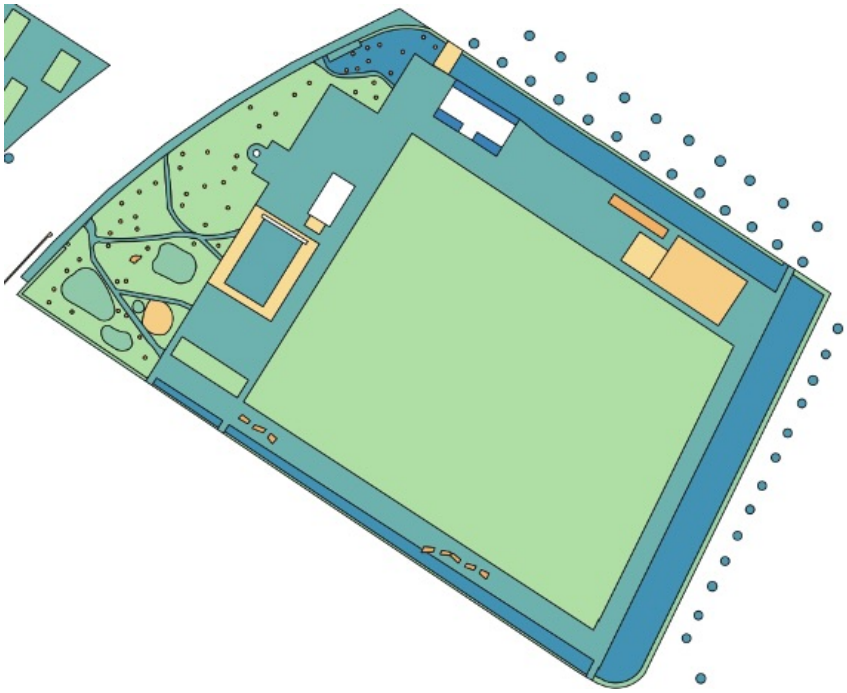


Figure 3.3: Example of the *Grünflächen* dataset of the city; Josefwiese colored by vegetation types as one of many attributes in dataset.

However, some limitations do exist for this dataset in the scope of this thesis. First, it exclusively covers greenspaces maintained by GSZ. This means that parks under cantonal or federal jurisdiction (such as Irchelpark) are absent. Second, it does not capture greenspaces beyond the city border, which may underestimate park access for residents in peripheral zones. And third, park borders are recorded from the perspective of maintaining an open space rather than displaying real-life/perceived park boundaries.

Since this dataset contains many different types of greenspace it needed to be prepared. All polygons from the same maintenance area (`Pflegeareale`) were dissolved with the aim to get a single-polygon greenspace unit in the city. This resulted in 2'622 polygons representing various types of greenspace (see Figure 3.4).

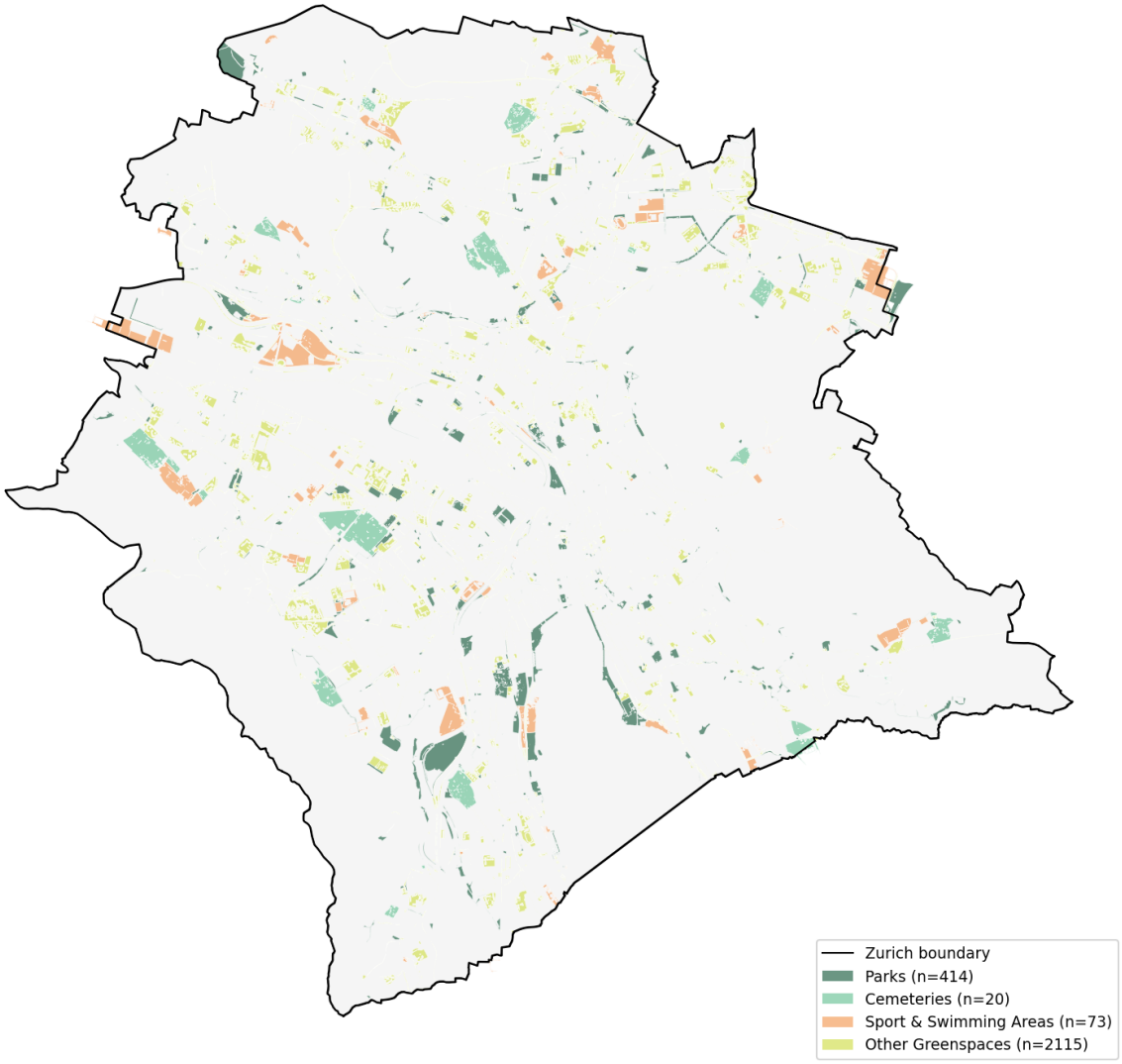


Figure 3.4: Polygons from *Grünflächen* dataset from the City of Zurich with different types of greenspace.

Federal swissTLM3D (2025)

The federal topographic landscape model *swissTLM3D* (swisstopo, 2025b) provides a comprehensive vector representation of Switzerland's physical and built environment. The dataset is available as open government data free of charge since 2021 and is provided in LV95 (EPSG: 2056). The version used in this study was released in 2025.

The layer `tlm_areale_nutzungsareal` was used during the dataset evaluation phase to validate and supplement the municipal greenspace dataset. This layer contains 802 polygon geometries from the object type (`objektart`) public park area (`Oeffentliches Parkareal`) in the whole Swiss territory. For the later park accessibility analysis, a buffer of 2 kilometers around the city was adopted. It ensures also capturing parks outside the city's borders. Residents on the outskirts of the city might also visit parks that are located

outside the official urban territory. Two kilometers were chosen as a buffer distance to get a broad enough border zone and encapsulate the later on 1.2 kilometer maximum of walking distance from parks (see Section 3.3.5). Within Zurich's city borders there are 78 with another 10 public park areas in the buffer zone (Figure 3.5).

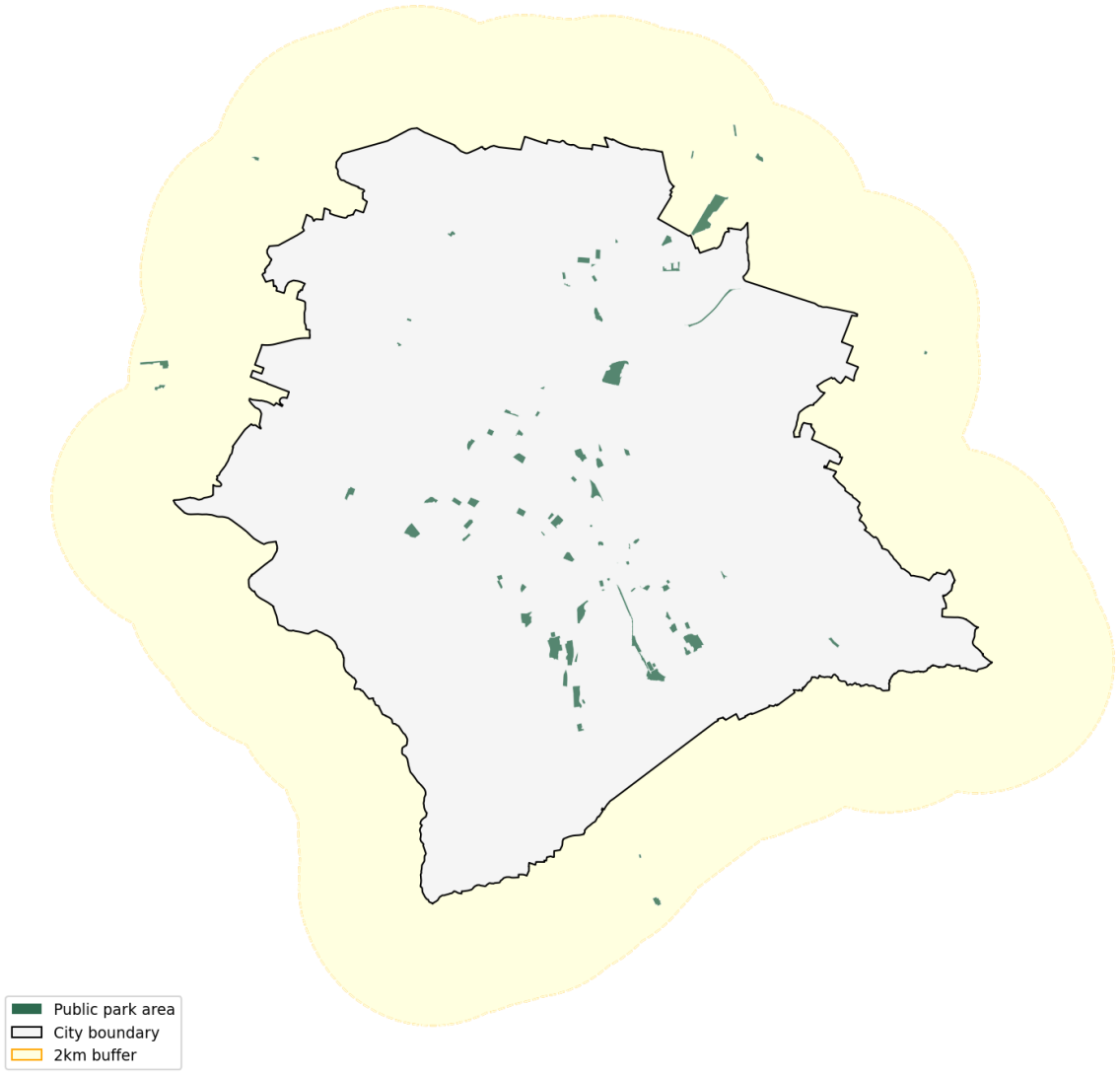


Figure 3.5: Map of all public park areas within the City of Zurich and a buffer of 2 kilometers (Source: Display of swissTLM3D Data).

This federal dataset offers additional information to the municipal dataset because it covers the whole Swiss territory. Therefore, it also captures the 2 km buffer around Zurich. As it was conducted by a federal department, it might differ from the municipal greenspace dataset. This deviation might not be significant but should be kept in mind when comparing it to the other datasets (see Section 3.2.2). Since this dataset consists simply of single polygons per park area, no dissolving was required for later use.

OpenStreetMap

OpenStreetMap (OSM), a collaborative, open-access geographic database, provides a tool called Overpass Turbo which enables the download of data collected. Tags and labels allow users to extract various spatial elements. Since there exist many different tags on OSM and data may be tagged in different ways, many different tags were tested. It ensures to find the most suitable data on parks.

To get a broad overview over existing greenspaces in Zurich, not only the most obvious tag `leisure = park` was used to find data points, but also tags like `leisure = garden`, `landuse = recreation_ground` and `landuse = grass`. See Section A.3 for more information on the tag selection. To capture the diversity of greenspaces which would later be filtered by set criteria, a wide-ranging approach in OSM data was preferred. The query initially included features for the whole Canton of Zurich, which then needed to be reduced to the area of the city plus buffer before it was further investigated. This resulted in 4'099 polygons with the following categories: 2'508 grass, 1'288 garden, 271 park and 32 recreation ground. In further inspection, the tag `grass` did not make sense to include. It captured sport facilities and other big meadow areas that upon manual inspection did not fit the park definition. Moreover, they largely overlapped with the other tagged features, making them redundant. Figure 3.6 shows the polygons without the grass category. As a pre-selection of possible park areas, the gardens were kept even though they seemed to be smaller polygons and included upon manual inspection community gardens. Again, a broad scope was preferred, to keep an open mind towards greenspace areas.

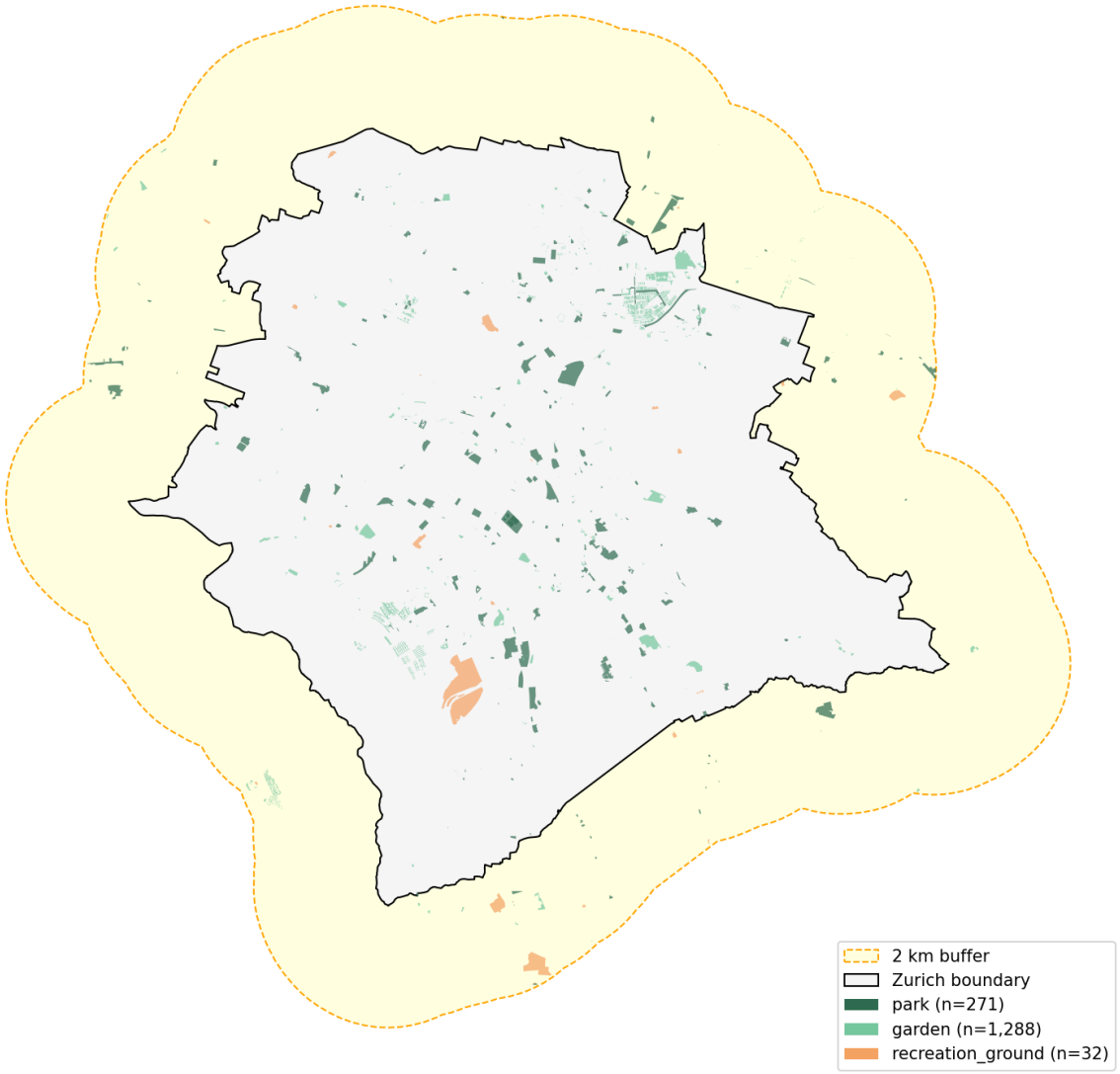


Figure 3.6: Polygons from OpenStreetMap query including parks, gardens, recreation grounds and others.

3.2.2 Park Dataset Filtering

Based on the three datasets, multiple filtering steps were carried out to generate a final park dataset that complies with the urban park definition from Section 2.2.1. Following this, five steps were executed: (1) filter by size, (2) exclude forest areas, (3) filter by main function, (4) spatial merge the three datasets and (5) manual inspection.

Step 1: Filter by Size

As a first step, the park selection follows a minimum size of 0.5 ha. This is consistent with broader literature on park size and ecosystem services as well as with the *World Health Organization (WHO)* recommendations (see Section 2.2.1). Furthermore, greenspaces below

this size threshold are unlikely to host the park elements assessed in this thesis. Looking at the literature (Section 2.2.1), the 0.5 ha threshold applied here is set deliberately below the lower bound of the cultural services range. Reason being to ensure a conservative inclusion of parks that may still function as meaningful recreational spaces. Still, it systematically excludes green fragments that do not fulfill a park function in any operational sense. Combined with WHO's recommendation and the fact that Zurich is a small city in the international comparison, this threshold seemed reasonable for this thesis.

As shown in Table 3.3, applying the 0.5 ha threshold resulted in a substantial reduction in the number of features across the municipal and OSM datasets. Notably, despite the large number of polygons removed, the total area decreased by a considerably smaller proportion. This indicates that the excluded features were predominantly small green fragments. Confirming that the filter effectively targeted minor greenspaces like street-side strips and traffic islands. All while retaining the majority of the total park area, which was the primary objective of this filtering step.

Table 3.3: Park datasets before and after the 0.5 ha size filter.

Dataset	Before (n)	After (n)	Removed (n)	Before (ha)	After (ha)
City of Zurich	2'622	358	2'264	862.0	691.6
OpenStreetMap	1'586	109	1'477	326.4	240.9
SwissTLM3D	88	64	24	134.5	127.8
Total	4'296	531	3'765	1322.9	1060.3

Note: After = features $\geq$ 0.5 ha retained.

Step 2: Exclude Forest Areas

The second step was to screen out remaining features that overlapped with areas officially categorized as forest, using the cantonal forest dataset (Canton of Zurich, 2017). Forest areas were excluded because, they differ fundamentally from managed urban parks in terms of infrastructure, recreational function and their usage (Hansmann et al., 2007; Wozniak et al., 2025). Features were removed if they overlapped with the forest layer by more than 25 percent of their area. While all datasets had few features overlapping slightly with the forest, a threshold of 10 percent overlap did not change the outcome of excluded features. Therefore, some testing resulted in 25 percent being a reasonable and representative share for overlap exclusion. This filter only excluded two features in total (Table 3.4). The minimal effect of this criterion is consistent with expectations. The size threshold had already removed most small green fragments likely to overlap with forest areas. Still, the remaining larger features correspond more to managed parks situated within the built environment of the city.

Table 3.4: Park datasets before and after the forest exclusion criterion.

Dataset	Before (n)	After (n)	Removed (n)	Before (ha)	After (ha)
City of Zurich	358	358	0	691.6	691.6
OpenStreetMap	109	108	1	240.9	240.3
SwissTLM3D	64	63	1	127.8	125.9
Total	531	529	2	1060.3	1057.8

Note: Features removed if overlapping with cantonal forest boundaries ≥ 25 percent (*Waldareal Kanton Zürich*).

Step 3: Filter by Main Function

The next step was to evaluate the functionality of the previously selected features. The municipal dataset was the simplest to filter in this regard. Looking at the attribute `Produkt`, the product type was recorded by the city. The four values that remained (i.e. emerged predominantly in newly dissolved greenspace polygons along values within dissolved unit) were: parks, cemeteries, sport/swimming grounds and other greenspaces. Cemeteries and sport/swimming grounds could be filtered out immediately, since their main function is clearly stated. Features from the type *weitere Freiräume* (other greenspaces) were manually evaluated. There were 181 features of which 93 included *Schulhaus* (school) in their name. This also lead to omission since greenspaces around school buildings have a different main function than parks. From the remaining 88, an additional 39 features included *Wohnsiedlung* (residential complex). They were also excluded since they do not primarily serve the function of a park but as greenspace around residential buildings. Find a full list of further keywords to filter out remaining function types in Section A.4. Table 3.5 shows that most features that were removed originated from the municipal dataset. The substantially higher removal in the City of Zurich's dataset reflects the broader scope of the municipal greenspace inventory. It encompasses all city-managed open spaces rather than parks specifically. Over half of the features belonged to the category *Other Greenspaces*. They comprise street-side vegetation, embankments and utility areas that do not fulfill a primary recreational park function.

Table 3.5: Park datasets before and after the main function keyword filter.

Dataset	Before (n)	After (n)	Removed (n)	Before (ha)	After (ha)
City of Zurich	358	149	209	691.6	333.8
OpenStreetMap	108	104	4	240.3	231.1
SwissTLM3D	63	60	3	125.9	118.0
Total	529	313	216	1057.8	682.9

3.2.3 Spatial Merge

After the filtering steps, the three individual datasets (municipal, OSM and swissTLM3D) were merged by a spatial and name-based overlapping. This meant that polygons that overlapped at least 50 percent of their area were considered the same. The duplicate was removed. This threshold was once again tested and considered the most representative. This merge resulted in the previous 277 features decreasing to 173 unique features: 113 features from the municipal dataset, 54 from OpenStreetMap and 6 from swissTLM3D (Table 3.6).

The low retention of swissTLM3D features after the merge (54 features removed from the original 60 features) reflects the substantial spatial overlap between this dataset and the municipal greenspace inventory. Reason being that both capture officially designated public park areas in Zurich. SwissTLM3D features were assigned lower priority in the merge. This lead to an overlap exceeding 50 percent, the municipal polygon was retained. The reduction of OSM features after the merge (104 to 54) reflects substantial overlap with the municipal dataset for well-known, larger parks. The 54 retained features represent areas not covered by the municipal inventory. Therefore, demonstrating the complementary value of OpenStreetMap as a secondary source.

Table 3.6: Park datasets before and after spatial merge.

Source	Before (n)	After (n)	Removed (n)	Before (ha)	After (ha)
City of Zurich	149	113	36	333.8	192.6
OpenStreetMap	104	54	50	231.1	108.4
SwissTLM3D	60	6	54	118.0	5.4
Total	277	173	104	682.9	306.4

Note: Where polygons from different sources overlapped by ≥50% of their area, the municipal dataset polygon was retained.

3.2.4 Manual Inspection and Adjustments

Finally, the remaining 173 features were manually inspected using Google Maps satellite imagery and StreetView to verify spatial delineation and compliance with the park definition established in Section 2.2.1. Table 3.7 summarizes the exclusion criteria applied during this inspection. While some criteria overlap with earlier filtering steps, manual inspection was necessary to identify cases that automated spatial methods could not reliably detect. For example, privately enclosed courtyards or narrow connector paths that met the size criterion but lacked a park-specific recreational function.

The manual review revealed two broad categories of false positives. The first covers areas with a distinct primary land use incompatible with the park definition adopted in this

Table 3.7: Criteria for manual exclusion of park polygons during quality control.

Exclusion type	Description	Reason for exclusion
Connector path	Long thin vegetated path between spaces	No recreational function or amenities
Functional green belt	Green strip surrounding swimming facilities or similar	Ancillary to primary land use, not an independent park
Private garden / courtyard	Vegetation within residential block interior	Not publicly accessible
Riverside path	Narrow vegetated band along watercourse	Below size threshold or not park-like, fragmented
Road strip	Narrow green strip along lanes	Not publicly accessible as recreational space
Sports field	Artificial turf or athletics infrastructure	Distinct land use, not a park
Unidentifiable remnant greenspace	Small patch without discernible purpose or amenities, often on steep slope	Cannot be defined as a park by function

thesis: sport fields and private gardens or courtyards were removed as they either serve a non-recreational function or are not freely accessible to the general public at all times. Even though the previous filtering step targeted non-park land uses, a substantial number of such features remained in the dataset. This is likely because the attribute information alone was insufficient to reveal their actual purpose without visual verification. The second category encompasses greenspaces that are formally vegetated but lack independent recreational character. For example, road strips, functional green belts surrounding facilities such as swimming pools, narrow riverside paths, long connector paths between spaces and small unidentifiable remnant patches (often located on steep slopes) that contain no amenities and serve no discernible park function. Public accessibility was treated as a non-negotiable prerequisite throughout. Any area not freely accessible to the general public was excluded regardless of its classification in the source datasets.

Beyond the binary inclusion decision, park geometries were adjusted where necessary. These modifications addressed three cases: polygons containing holes in unreasonable locations, partially missing park area in the source layer and park borders extending beyond the real-life scope of the feature. A notable example of the first case are small gaps introduced by the greening department (*Grünflächen* layer) for fountains or similar smaller structures. They are formally excluded from maintenance polygons but constitute integral parts of the park area and must be counted as such.

Two cases required a deliberate spatial aggregation decision: along both sides of the

lake of Zurich are long recreational belts that were segmented into multiple features. This is due to the fact that area such as for example Zürichhorn and the adjacent Blatterwiese are officially considered as separate units but do not display any physical barriers. So looking merely at park count, the zones along the lake would feature a high count of parks. This, even though the park areas could also be conceptualized as one long park belt along the water. The decision of whether to consider them as one or multiple parks would affect accessibility analysis. In order to allow individual park characteristics assessment, neighboring parks were maintained as separate spatial units, with area weighted in the accessibility score rather than simple park count (see Section 3.3).

In hindsight, the previous filtering could have involved also a step where amenities were inspected. It turns out that comparing the manually approved features with the sorted out polygons, the 104 approved ones had a mean 23.6 bench count. The 69 filtered out only had a mean of 3.3 benches. From the 104 approved parks, only 6 parks do not contain any benches. Following these steps, a final park dataset was retained. The spatial distribution of the selected parks is shown in Section 4.1. The final selection step resulted in the following change in park count and area:

Table 3.8: Park dataset before and after manual review.

	Before (n)	After (n)	Removed (n)	Before (ha)	After (ha)
All parks	173	104	69	306.4	176.5

3.3 Park Accessibility Measurement

3.3.1 Rationale and Approach

Park accessibility was operationalised as a weighted sum of park areas reachable from each residential building within defined pedestrian network distances. Each park's contribution is scaled by its size in hectares and is counted by the network distance from the building. This approach was preferred over Euclidean distance buffers because the straight-line approach systematically overestimates accessibility in dense urban environments. Physical barriers such as railway lines, water bodies and motorways constrain actual pedestrian movement (J. Li et al., 2022; Tatit et al., 2024). Network-based accessibility measures are consequently considered more valid indicators of experienced access. Particularly in cities such as Zurich where topographic and infrastructural barriers are pronounced. For example the train tracks in the separating district 5 from district 4 depict a clear physical barrier for pedestrians.

The analysis followed a building-centered logic (Figure 3.7). Each residential building in the study area constitutes one observation and access scores are subsequently aggregated

to the level of statistical zones to enable socioeconomic comparison later on. Aggregation was population-weighted rather than building-weighted. This way multi-family residential buildings contribute proportionally more to a zone's mean score than small outbuildings or garages (see Section 3.3.7). Table 3.9 shows the symbols used in the formulas in this chapter.

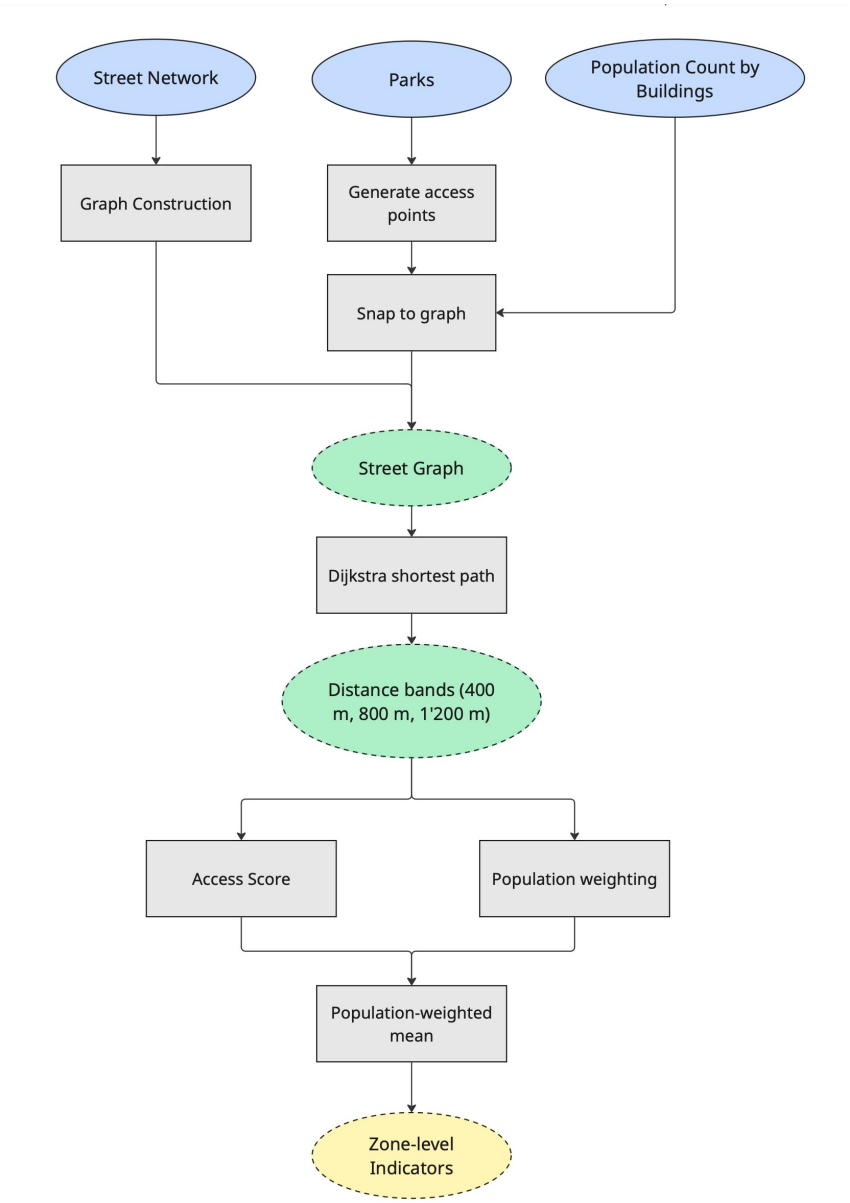


Figure 3.7: Scheme of workflow for the network-based park accessibility analysis.

3.3.2 Data

Street Network

For the buffering of the parks, the street layer from swissTLM3D was used. The layer for the street network is called `tlm_strassen_strasse` and contains all streets and (walking)

Table 3.9: Notation used throughout Sections 3.3–3.7

Symbol	Description
i	Index for residential building
j	Index for park or forest polygon
z	Index for statistical zone
k	Index for path/way segment
d_{ij}	Network distance between building i and park/forest j (m)
$w(\cdot)$	Distance-decay weight function
$area_j$	Area of park j (ha)
pop_i	Population assigned to building i
R_i	Set of parks reachable from building i within 1'200 m

paths within Switzerland. So the layer contains both drivable and walkable links. For calculating parks within a certain reach of residential buildings, the street network was clipped to an extent to the City of Zurich plus a buffer (2 km). As residents in peripheral areas might be able to access parks outside the city, the two kilometer were considered sufficient to ensure to include all possible parks along city borders.

Residential Population Count

Residential building-level population counts were obtained from the Swiss Federal Statistical Office's STATPOP dataset (`statpop_buildings_zurich`) under a data sharing agreement with the Urban Analytics group at the Department of Geography, University of Zurich. It provides geocoded building locations in LV95 coordinates alongside population counts per building. Buildings with missing or zero population counts were excluded prior to analysis. The analysis only retained structures with at least one registered resident. Due to the personal nature of the underlying data, access was restricted to university-managed devices and secure virtual machines. All computations were performed within this controlled environment. For the purposes of this thesis, building-level population was only used in the computation of access scores. They were later aggregated to statistical zone level described in Section 3.3.7.

3.3.3 Graph Construction

The street network was modeled as an undirected weighted graph. Each node corresponds to a rounded coordinate pair and each edge carries a weight equal to the Euclidean length of the corresponding street segment in meters. Graph construction was performed using the `NetworkX` library in Python (Hagberg et al., 2008).

3.3.4 Snapping Buildings and Parks to Network

Residential buildings were derived directly from the STATPOP dataset. With point geometries constructed from the LV95 coordinate pairs provided in the source file. No additional filtering by building use was required, as the dataset is restricted to residential buildings by construction.

Both buildings and park access points were snapped to the nearest graph node using a k-d tree spatial index (`scipy.cKDtree`) for computational efficiency. For buildings, snapping distance was recorded and later added to the network distance to obtain a complete door-to-park path length. Buildings whose nearest graph node exceeded a snapping distance of 200 meters were excluded from the analysis. Such distances indicate either isolated structures far from the pedestrian network or geometric mismatches unlikely to reflect actual residential locations. Park access points were generated by interpolating points at regular 30 m intervals along the exterior boundary of park polygons. A single centroid was avoided to account for the spatial extent of parks and the fact that park entrances are distributed along their perimeter (Apparicio & Seguin, 2006). The minimum snapping distance across all access points of a park was added to the Dijkstra network distance. The distance from the park edge to the nearest network node was then approximated.

3.3.5 Dijkstra Shortest-Path Computation

Shortest-path distances from each park to all reachable buildings were computed using Dijkstra's algorithm as implemented in `NetworkX` (Dijkstra, 1959; Hagberg et al., 2008). To avoid the excessive computational cost of running a separate Dijkstra path from every building ($n \approx 57'000$), the direction of path was reversed. One multi-source Dijkstra call was issued per park. To do so, the set of snapped park boundary nodes as simultaneous sources was used. Then, a maximum path of 1'200 meters cut off longer ways. This strategy reduces the number of graph paths from the number of buildings to the number of parks. It yielded a substantial reduction in computation time while producing identical distance results.

For each building, the total access distance to a given park was computed as the sum of three aspects: (i) the building's snapping distance to the nearest network node, (ii) the shortest network path distance between that node and the nearest park boundary node and (iii) the park's minimum snapping distance to the network. Where multiple building records shared the same graph node (a consequence of buildings located on the same street segment) each was assigned its own snapping distance and thus a distinct total distance.

3.3.6 Distance Thresholds and Access Score

Three distance thresholds were applied, informed by literature on urban greenspace access and established thresholds (Boone et al., 2009; Cracu et al., 2024; Grunewald et al., 2019; Sugiyama et al., 2019): 400 meters, 800 meters and 1'200 meters. These distances represent (based on an average walking speed of 4.8 km/h) a travel time of 5, 10 and 15 minutes respectively. For each building i, the park accessibility was computed as a weighted sum of park area across all parks reachable within 1'200 meters:

$$s_i = \sum_j area_j \cdot w(d_{ij}) \tag{3.1}$$

s_i	park accessibility score of building i
$area_j$	area of park j (ha)
d_{ij}	network distance between building i and park j (m)
$w(\cdot)$	distance-decay function, defined in Equation 3.2

with notation as defined in Table 3.9. The distance-decay function $w(\cdot)$ is defined as:

$$w(d_{ij}) = \begin{cases} 0.75 & \text{if } d_{ij} \leq 400 \\ 0.50 & \text{if } 400 < d_{ij} \leq 800 \\ 0.25 & \text{if } 800 < d_{ij} \leq 1'200 \\ 0 & \text{if } d_{ij} > 1'200 \end{cases} \tag{3.2}$$

This area-weighted formulation gives greater importance to larger parks and closer parks simultaneously, reflecting the assumption that both proximity and park size contribute to the recreational benefit experienced by residents (Wolch et al., 2014). The sensitivity of zone-level accessibility rankings to this weighting scheme was assessed by three alternative decay specifications (see a robustness check in Section A.5).

3.3.7 Population Weighting and Zone-Level Aggregation

Building-level population counts were taken directly from the STATPOP source file, in which each record already carries a resident population count. As buildings with zero or missing population were excluded, all buildings retained in the analysis carry a positive population weight. The population-weighted mean park access score for zone z was computed as:

$$\bar{s}_z = \frac{\sum_{i \in z} pop_i \cdot s_i}{\sum_{i \in z} pop_i} \tag{3.3}$$

$\bar{s}_z$	population-weighted mean park access score of zone z
pop_i	population assigned to building i
s_i	building-level access score (Equation 3.1)

Lake zones, identified by name as *See Ost*, *See West*, *See Süd-West* and *See Nord*, were excluded from the subsequent regression analysis as they contain no residential population.

In addition to the weighted mean score, the following zone-level indicators were derived for descriptive analysis: total population per zone ($\sum p_i$); share of buildings with at least one park within 400, 800 and 1'200 m (`pct_with_400m` etc.) and an unweighted mean score (`mean_score_unw`) retained for sensitivity comparison. The correlation between the weighted and unweighted mean scores across the zones was inspected to assess whether population weighting materially altered the spatial pattern of access. The two measures were very strongly correlated (Pearson $r = 0.995$, Spearman $\rho = 0.994$, both $p < 0.001$), indicating that population weighting had a negligible effect on the spatial pattern of zone-level park access scores. Global Moran's I was computed for the zonal-level park access to assess the degree of spatial clustering in the outcome variables. Furthermore, it informs the choice of spatial regression specification.

3.4 Park Characteristic Measurement

Park characteristics were assessed individually across the following attributes: size, vegetation cover, path density and infrastructure elements including benches, fountains and public toilets. Each attribute is analyzed as a separate variable rather than aggregated into a composite index. This preserves interpretability and avoids assumptions about the relative weighting of ecological and recreational dimensions (Rigolon, 2016; Taylor & Hochuli, 2017).

3.4.1 Park Characteristics

Vegetation Cover

Nature is considered a defining characteristic of urban parks and a primary driver of their recreational and ecological value (Kaspar, 2012). The significance of this park characteristic therefore entails thorough evaluation. This thesis attempts to implement this by using three methods to measure green coverage. To quantify the vegetation cover of each park, the Normalized Difference Vegetation Index (NDVI) was calculated. Furthermore, the tree canopy was evaluated per park, since the NDVI might misrepresent vegetation cover in some parks (mainly in the city center). Third, the parks that were contained in the municipal greenspace dataset (Section 3.2.1) could be analyzed regarding vegetation types. These three techniques were combined to create a complete picture of vegetation cover of

all parks involved in this thesis.

Normalized Difference Vegetation Index To get a spatially continuous measure of vegetation cover for each park, the SWISSIMAGE RS dataset (swisstopo, 2025a) produced by the Federal Office of Topography (*swisstopo*) was used. SWISSIMAGE RS consists of orthorectified individual image strips captured by aerial survey that provide four spectral channels: Near-Infrared (NIR, 808–882 nm), Red (619–651 nm), Green (525–585 nm) and Blue (435–495 nm). The dataset is available in LV95 (EPSG:2056) at a ground resolution of 0.1 m. This thesis used an extract from the year 2025 covering the City of Zurich and the buffer zone of 2 kilometers. The respective images were recorded in March 2025. Even though early spring is not ideal to capture vegetation cover, results are sufficient for the purpose of this thesis. SWISSIMAGE RS is not a composite or seamless mosaic. Each image strip retains its individual acquisition timestamp, encoded in the filename. This concludes that spectral values may vary between adjacent strips due to differences in illumination or weather conditions. The availability of a dedicated NIR channel makes SWISSIMAGE RS particularly suited for vegetation analysis. Vegetation reflects solar radiation predominantly in the near-infrared spectrum (Ju et al., 2024). This property allows the computation of the Normalized Difference Vegetation Index (NDVI). The NDVI looks at the contrasting reflectance behavior of vegetation in the red and near-infrared portions of the electromagnetic spectrum and is defined as:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR} + \text{Red}} \tag{3.4}$$

where NIR denotes the reflectance in the near-infrared band (808–882 nm) and Red the reflectance in the red band (619–651 nm). NDVI values range from -1 to 1. Values near 1 indicate dense photosynthetically active vegetation. Values near 0 correspond to bare soil or sealed surfaces. Negative values are typically associated with water or built environment.

The share of pixels within each park polygon exceeding a threshold of 0.3 was created the vegetation score. This choice was motivated by the bimodal distribution of NDVI values in urban environments. Sealed surfaces and vegetated areas form two distinct clusters, such that mean value lands between them and would represent neither meaningfully. Percent vegetation cover instead captures the proportion of a park's surface that is actively vegetated. This is directly interpretable and more robust to the distributional characteristic. The threshold of 0.3 is consistent with established conventions in urban remote sensing. Values above this level are consistently associated with photosynthetically active vegetation (Ju et al., 2024).

Tree Canopy Supplementary to the NDVI, the tree canopy per park was investigated to get a more realistic view of parks. To do so, the tree cadaster (*Baumkataster*,

Grün Stadt Zürich (2026a)) provided by the City of Zurich was utilized. It records the location and estimated crown diameter of individually city-owned trees across the city. Crown footprints are available as precomputed polygon geometries in the layer `gsz.baumkataster_kronendurchmesser`, which were joined to the tree identifier (`baumnummer`). Trees classified exclusively as street trees (*Strassenbaum*) were excluded prior to analysis. They are situated in road space rather than in park greenery. Trees categorized as *Strassenbaum (A)*, which are located along green areas (like a park), were retained due to their park proximity.

Crown polygons intersecting each park boundary were identified via spatial join. Subsequently, they are clipped to the park extent, ensuring that only the portion of a crown located within the park contributed to the canopy estimate. To prevent double-counting in areas of overlapping canopies, all clipped crown polygons within each park were dissolved into a single union geometry. Only then, the area was calculated. The resulting canopy area (m^2) was divided by the total park area to yield a per-park *canopy share* (`canopy_share_pct`), expressed as a percentage and capped at 100 percent. Parks for which no cadaster entries were recorded received a canopy share of NaN. The derived variable `canopy_area_m2` and `canopy_share_pct` were subsequently merged into the park dataset.

Of the 104 parks, only 15 did not contain any trees. Furthermore, from these 15 parks without trees, 11 are located outside the city border. This makes sense for them to not have any trees as the tree dataset only contains trees in the city. Since NDVI-derived vegetation cover is available for all 104 parks, the absence of canopy data for these parks does not substantially compromise the assessment.

Land Cover Vegetation Types For the parks captured by the municipal greenspace dataset (Section 3.2.1), very detailed information about surface coverage is available. This approach, however, can only be applied to the parks that are covered by the greenspace dataset of the city. The dataset includes an attribute `Vegetation Type` (*Vegetationstyp*) that names all different types of land cover within a park area. Section A.6 contains a list of land cover types incorporated in the municipal dataset and their categorization to vegetation and non-vegetation.

To calculate vegetation cover per park, the land cover polygons were first clipped to the park boundaries. Then, each clipped polygon was classified as either vegetation or non-vegetation based on keyword matching against the *Vegetationstyp* label. The vegetation area per park was aggregated by dissolving all vegetation polygons within each park boundary. The resulting area was divided by the total clipped land cover area to yield a per-park vegetation share (`vegetation_percent`). Parks for which no land cover polygons were available in the municipal dataset (either because they are located outside the city boundary or are not maintained by the city's greening department (GSZ)) received

a value NaN. In total, 90 of the 104 parks could be assigned a vegetation cover value through this approach.

Comparison of Vegetation Measurements To get a final vegetation cover measurement, the three approaches were compared. Even though the NDVI is the most continuous measure for greenspace, manual inspection revealed that it did not represent all parks equally accurately. Furthermore, as the parks covered by the municipal dataset contain highly detailed information about surface coverage, it will be the primary source of information for these parks.

To assess the convergence between the three vegetation measures, pairwise Spearman rank correlations (Nesbitt et al., 2019; Spearman, 1904) were computed across all parks that covered all three measures of vegetation ($n = 94$). NDVI vegetation share and land cover vegetation share showed strong agreement ($\rho = 0.76$, $p < 0.001$). It confirmed that both capture the same underlying dimension of surface greenness through different methods. Tree canopy coverage, however, correlated weakly with both measures ($\rho \leq 0.16$, $p > 0.05$). This reflects its conceptual difference on vertical vegetation structure rather than overall surface greenness. These results informed the decision to treat the NDVI and land cover measures equally, while ignoring the tree canopy measure for this type of measurement.

Also important to evaluate, were parks missing in the comparison of the three measures. In total 12 parks do not contain any city trees or land cover polygons from the city's datasets. This makes sense because 11 of them are located outside the city's boundary. The one park inside the city's borders with no data for both trees and land cover is the *Universitätsspital Park*.

For parks contained in the municipal dataset, the values from that dataset are used and for the remaining parks, the values are derived from the NDVI calculation. Because the comparison showed a high degree of agreement between NDVI and land cover, the two measures are treated as interchangeable in this thesis. The final list of parks and their vegetation cover along the other park characteristics is attached in Section A.7.

Path Density

To measure the paths available in each park, three complementary datasets on the pedestrian and cycling network were combined. The primary source was the City of Zurich's pedestrian and cycling network (City of Zurich (2022), layer `taz_mm.tbl_routenetz`), which contains 40'294 line segments of the municipal route network in LV95 (EPSG:2056). As a secondary source, the swissTLM3D street network (`streets_tlm.gpkg`) was consulted again (see also Section 3.3.2). Only filtered walkable segment types were used: *Verbindung* (connection) and *Markierte Spur* (marked lane). This yielded 22'617 segments after filtering. As a tertiary source, OpenStreetMap ways were retrieved via the `osmnx` library using

the highway tags `footway`, `path`, `pedestrian`, `cycleway`, `living_street` and `track`. It resulted in 43'044 line segments for the Zurich area (and buffer of 2 kilometers).

To quantify the pedestrian infrastructure within parks, the total length of walkable paths was computed and normalized by park area. Path density d_p for park p is defined as:

$$\rho_j = \frac{\sum_{k=1}^{n_j} l_k}{area_j} \tag{3.5}$$

ρ_j	path density of park j (m of walkable path per m^2)
l_k	length of retained way segment k (m)
n_j	total number of retained segments within park j
$area_j$	area of park j (m^2)

The resulting indicator `ways_m_per_m2` is expressed in meters of walkable path per square meter of park area (Kirsteina et al., 2025). The City of Zurich pedestrian and cycling network served as the primary and most trusted source. The swissTLM3D network which was added as the secondary source, was not filtered as street segments in parks would most likely be walkable paths anyways. OpenStreetMap ways were included as a tertiary fallback. Motorized road types were excluded in all cases.

Each source was clipped to the park polygon extended by a 3 m buffer to capture paths running immediately along park boundaries. This buffer was also tested in 8 m and 5 m but proved to be most adequate in 3 m. De-duplication was subsequently performed. SwissTLM3D segments were only retained where they did not intersect the city network within a 2 m tolerance buffer. OSM segments were only retained where they did not intersect either the city or swissTLM3D segments within the same tolerance. This yielded a final combined dataset of 2'813 segments of which 2'159 originated from the city network (90'282.8 m), 317 from swissTLM3D (12'750.8 m) and 337 from OSM (6804.7 m). Considering the total segment length of each data source provides insight into the type of segments. It can be assumed that OSM segments are significantly shorter than the segments from the other two sources. The dominance of the city data confirms that the municipal network provides near-complete coverage within parks. SwissTLM3D and OSM contributed only marginally. Since the city's dataset does not include streets outside the city's borders, paths in parks in the 2 km city buffer are mostly covered by the swissTLM3D and OSM datasets. Furthermore, the lower contribution of swissTLM3D likely reflects the thematic overlap between the two official datasets. Paths recorded by the city's pedestrian network are largely also captured in the swissTLM3D data, resulting in near-complete de-duplication.

For each of the 104 parks, the total length of all retained segments was summed (`ways_total_m`) and divided by the park's polygon area. This resulted in the path density per park. Only one park was found with no ways. It received a value of zero. The resulting indicator ranges from 0.011 to 0.294 m/m^2, with a median of 0.0583 m/m^2.

The reliability of the resulting values was assessed through visual inspection in QGIS. The combined way segments were overlaid against the park polygons for a random sample of parks. Where path density values were high, parks were more formally structured with dense footpath networks. Parks with low values corresponded to open meadow areas with few delimited paths.

Bench Density

For each amenity type (benches, fountains and public toilets), the City of Zurich's official open data served as primary source. Similar to the path method, OSM data was used as in the 2 km buffer zone. Furthermore, the OSM data was also used as supplementary source within city borders to check the completeness of the municipal datasets. On a federal level, no sufficient bench datasets were found.

The city provides a dataset including all benches (*Sitzbankkataster*, Grün Stadt Zürich and Tiefbauamt Zürich (2024)) located within city borders that are owned by the greening department (*Grün Stadt Zürich, GSZ*) and the civil engineering department (*Tiefbauamt Zürich, TAZ*) as of February 2024. This dataset contains 7'197 benches in total. For parks not (fully) covered by the city cadaster (primarily those located within the 2 km buffer zone outside the city boundary) bench locations were additionally retrieved from OpenStreetMap using the `amenity=bench` tag.

Bench counts were derived by spatially joining bench point features from both sources (city and OSM) to park polygons extended by a 3 m buffer. This proximity zone ensured capturing benches immediately along park boundaries. Furthermore, this buffer would compensate for park borders diverging slightly from reality. OSM benches falling within 2 m of an city bench were discarded to avoid double-counting. This yielded a combined dataset of 2'883 benches, of which 2'310 originated from the city cadaster and 573 from OSM. For each of the 104 parks, the total number of retained benches was summed (`bench_count`) and divided by the park area to obtain a normalized density (`bench_per_m2`). Parks for which no benches were found received a value of zero, which applied to 17 parks. The resulting indicator ranges from 0.0001 to 0.0121 benches/m^2, with a median of 0.0022 benches/m^2.

To validate results, a visual inspection on QGIS was conducted overlaying the bench point features with a map of the parks and furthermore viewing GoogleMaps images.

Public Toilet Availability

Public toilets as an essential public space service are recognized by literature as one of few important urban park elements (Kaczynski et al., 2008). Their locations were obtained from the *Züri WC* dataset published by the City of Zurich as an open government data (City of Zurich, 2026d). The dataset provides point geometries for all public toilet facilities

within the municipal boundary. As the dataset is updated on demand rather than at fixed intervals, it represents a current snapshot. Data was newly retrieved in June 2026. Parks located outside the city's borders were investigated manually through GoogleMaps images.

An initial spatial join with park polygons was extended by a 10 m buffer. That is wider than the 3 m applied to other amenity types, since toilet buildings are frequently positioned immediately outside mapped park polygons. The join yielded toilet counts per park. Since these counts showed that a majority of parks did not have close access to at least one public toilet, manual inspection was considered necessary. The manual check was also needed because several parks known to contain public toilet facilities recorded a count of zero. This indicated that the *ZüriWC* point geometries does not consistently fall within the buffered park polygons or were simply not included in the dataset.

To address this, toilet presence was verified manually for parks with a count of zero through two complementary sources: the City of Zurich's official park information pages (*Grün Stadt Zürich*[1]) and visual inspection via Google Maps. Where discrepancies between the spatial join result and the manual verification were found, the manually verified presence was retained as authoritative. This procedure corrected counts predominantly by adding facilities missed by the spatial join. Given the unreliability of the spatial intersection for this attribute, public toilet presence is represented as a binary indicator (`toilet_available`: 1 = present, 0 = absent) rather than a normalized density. As one single public toilet available per park is already of substantial value, a density measure was deemed unnecessary.

Fountain Availability

Fountains as a source of drinking water in Zurich, provide an essential part of recreational time in urban parks (Kaczynski et al., 2008). Analogously to the public toilets approach, the locations of fountains were collected by the municipal *Brunnen* dataset which is provided by the City of Zurich as open government data (City of Zurich, 2026b). Similar to the public toilet dataset, the *Brunnen* dataset includes point geometries for publicly maintained fountains inside the city borders. The data is also updated on demand and was retrieved newly in June 2026 to get a recent picture of fountains in the city. For parks lying outside the city's borders, manual inspection upheld the fountain availability.

A spatial join was conducted with park polygons extended by 3 m (like with the benches). This buffer is smaller than the public toilet buffer because most fountains are not along streets but rather inside a park if present at all. This way, a fountain count per park was yielded and an attribute (`fountain_available`: 1 = present, 0 = absent) was generated which would show a binary indicator similar to the public toilet data. The 41 parks without any fountains were manually inspected to validate and complement

[1] `https://www.stadt-zuerich.ch/de/stadtleben/sport-und-erholung/park-und-gruenanlagen.html`

the findings from the spatial join. After the manual check, 26 parks remained without fountains.

3.4.2 Zone-Level Aggregation of Park Characteristics

For each park characteristic a corresponding zone-level score was computed following the same procedure applied to the park accessibility score. For each building, the decay-weighted mean characteristic value of all reachable parks within 1'200 m network distance was calculated as:

$$char_score_i = \frac{\sum_{j \in R_i} v_j \cdot w(d_{ij})}{\sum_{j \in R_i} w(d_{ij})} \tag{3.6}$$

$char_score_i$	decay-weighted mean characteristic value for building i
v_j	characteristic value of park j (e.g. vegetation share, bench density)
R_i	set of parks reachable from building i within 1'200 m with a non-missing value for the characteristic in question
$w(\cdot)$	distance-decay function, defined in Equation 3.2

Unlike the park accessibility score, weighting each park by its area and capturing the cumulative amount of greenspace reachable, characteristic scores are computed as a weighted mean. This ensures that the resulting score reflects the average quality level of reachable parks rather than the sum of characteristics/amenities accessible. This also keeps the two dimensions (quantity of access and quality of provision) analytically separate. For `toilet_available` (binary), the resulting score represents the decay-weighted share of reachable parks equipped with a toilet. Buildings for which no reachable park carries a valid value for a given characteristic are assigned a missing value. They are excluded from the zone-level aggregation for that variable.

Zone-level scores were then derived by population-weighting the building-level scores following Equation 3.3, as described in Section 3.3.7. Lake zones were excluded from subsequent analysis similar to previous steps. To assess the degree of spatial clustering in the resulting zone-level characteristic scores, Global Moran's I was computed for each variable following the same procedure applied to the park and forest accessibility scores (see Section 3.3).

3.5 Forest Accessibility

Ignoring forest areas in Zurich would result in a flawed analysis, as many statistical zones along the city border contain a considerable share of forest. As noted in Section 1.5.2, forests

cover approximately a quarter of the city's surface. To account for this, two forest datasets were evaluated: the land cover layer from the swissTLM3D dataset (swisstopo, 2025b), which includes categories such as `Wald`, `Wald offen`, `Gebueschwald` and `Gehoelzflaeche`, as well as the cantonal forest dataset (Canton of Zurich, 2017). The cantonal dataset was last updated in 2017/2018 as part of the periodic revision of the official cadastral survey (*Periodische Nachführung der Amtlichen Vermessung*). A comparison of the two datasets revealed that the swissTLM3D land cover layer includes a substantial number of small-scale vegetation patches within the city center (most notably `Gehoelzflaeche`) which are not comparable to continuous forest areas in terms of their effect on park availability (Figure 3.8). The cantonal dataset, by contrast, explicitly excludes woody vegetation patches below 800 m^2 (*Feldgehölze*). It therefore captures only larger, continuous forested areas. And thus provides a more thematically consistent basis for controlling for forest cover in the subsequent analysis.

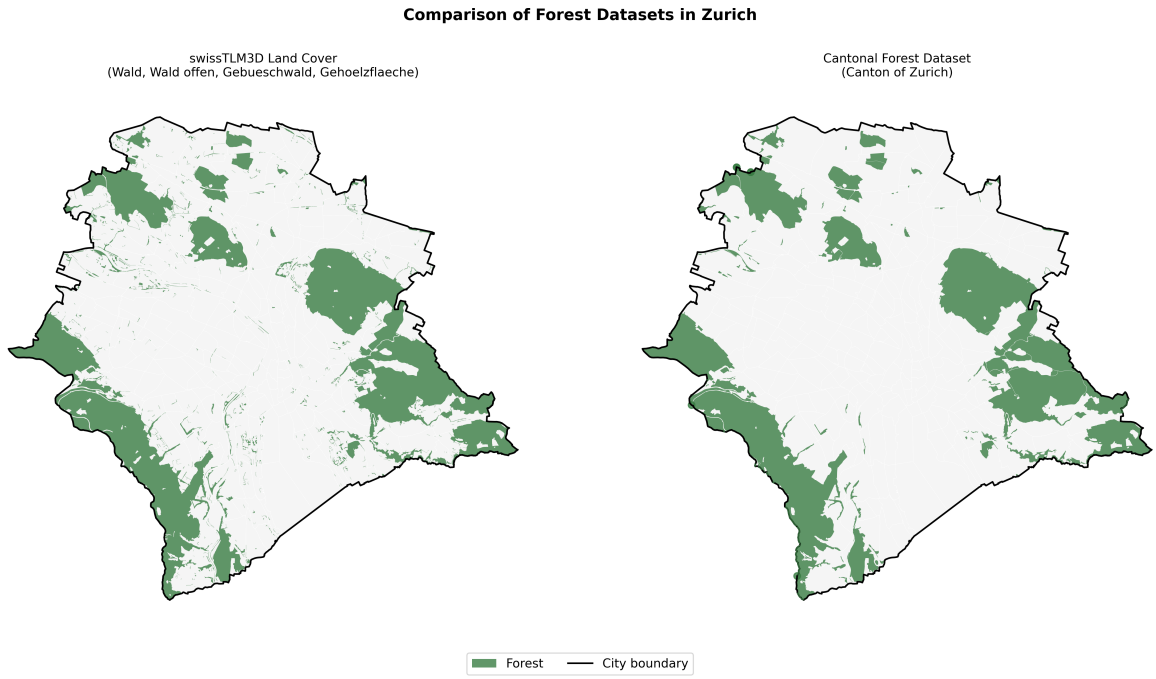


Figure 3.8: Comparison of forest datasets in Zurich. Left: swissTLM3D land cover layer including `Wald`, `Wald offen`, `Gebueschwald` and `Gehoelzflaeche`. Right: Cantonal forest dataset of the Canton of Zurich.

Because the park access score does not account for the proximity of forests, zones with low park access but high forest access would otherwise be misjudged regarding greenspace access. Including forest accessibility as an additional greenspace measure puts the effect of park provision into perspective for the broader availability of greenspace.

The procedure follows the same network-based approach used for park accessibility (Section 3.3), with the park dataset replaced by the cantonal forest polygons. The cantonal forest dataset was clipped to a 2 km city buffer around to also capture forests immediately outside Zurich. They remain accessible to city residents who live in peripheral areas. Entry

points were generated at 50 m intervals along each forest perimeter and snapped to the street network. A multi-source Dijkstra search was then run per forest polygon with a 1'200 m cutoff.

The forest accessibility score follows the same area-weighted formulation as the park accessibility score (Equation 3.1). However, the area of each forest polygon is capped prior to weighting at the 75th percentile of the park area distribution. This was to prevent large contiguous forest patches from numerically dominating the score relative to parks.

$$forest_score_i = \sum_j \min\Big(area_j^{forest},\, CAP\Big) \cdot w(d_{ij}) \tag{3.7}$$

$forest_score_i$	forest accessibility score of building i
$area_j^{forest}$	area of forest polygon j (ha)
CAP	75th percentile of the park area distribution (Equation 3.1)
d_{ij}, $w(\cdot)$	as defined above

Zone-level scores were derived by population-weighted aggregation following Equation 3.3. The low correlation between forest and park access scores across zones confirms that the two measures capture distinct spatial patterns. It also further justifying their separate treatment in the analysis.

3.6 Baseline Greenness

Beyond its use as a park quality attribute, vegetation cover was also estimated at the level of statistical zones. It was implemented as a supplementary indicator of neighborhood-level greenness or 'baseline greenness'. This zone-level measure is distinct from park vegetation in that is captures all vegetated surfaces within a zone (including trees, private gardens, green roofs and other non-park greenery) rather than vegetation within park boundaries alone. Thus it provides a broader picture of the green environment that residents are exposed to in their daily surroundings.

The same SWISSIMAGE RS dataset introduced in Section 3.4.1 was used as the data source for this analysis. For each of the 216 statistical zones, the share of pixels exceeding an NDVI threshold of 0.3 was computed from the 2025 NDVI surface. It is referred to as *percent green cover*. This indicator captures the actively vegetated proportion of a zone's surface, irrespective of whether that vegetation is located within a formal park.

Further reasoning was that residents of zones with high general vegetation cover (e.g. street trees, private gardens or other non-park greenery) may experience a different relationship to park access than residents in mostly sealed/non-green areas. That is regardless of the parks formally available to them (Ke et al., 2023). Including baseline greenness helps to isolate the specific contribution of parks from the broader green

environment of an area.

The Normalized Difference Vegetation Index (NDVI) was computed from the SWISSIMAGE RS imagery introduced in Section 3.4.1, using the NIR and Red channels as defined in Equation 3.4.

To assess the degree of spatial overlap between the three greenspace measures used in this thesis (park accessibility, forest accessibility and baseline greenness), Spearman rank correlation coefficients were computed pairwise between the three measures (see Section 4.2.4). This step precedes the inequality analysis and serves to characterize the relationship between the three measures independently of the socioeconomic/demographic predictors.

3.7 Socioeconomic and Demographic Indicators

To examine the relationship between park accessibility and socioeconomic conditions, four zone-level indicators were selected as predictors: median income, share of foreign nationals, shares of elderly residents (age 65+) and share of youth (age 0–15). These variables operationalize two conceptually distinct but related dimensions of potential disparities (socioeconomic and demographic) that are commonly used in the urban greenspace inequality literature. Income and nationality composition serve as proxies for economic and structural inequality at the zone level. Much of the greenspace inequality literature, particularly from North American contexts, frames structural disparities through the lens of race and ethnicity (Abercrombie et al., 2008; Jepson et al., 2025; Maroko et al., 2009; Sister et al., 2010).

In the Swiss context, nationality or citizenship status is a more institutionally and statistically meaningful proxy for structural marginalization. Residential segregation and access to public resources are more closely tied to migration background and legal residency status than to racial categories. The age variables capture demographic vulnerability by identifying groups that are both more dependent on accessible public greenspace and less able to compensate for its absence through private alternatives (Enssle & Kabisch, 2020; Poppe et al., 2022; Sugiyama et al., 2019).

All four indicators are available at the statistical zone level from the city's statistical office and refer to the reference year 2022, the most recent year available for all four indicators. Choosing a year where all indicators are available ensures consistency with the spatial framework introduced in Section 3.1.

3.7.1 Median Income

As the first socioeconomic variable, median taxable income serves as a key proxy for the neighborhood-level economic status. The data were obtained at the statistical zone level

upon special request to the city's statistical office (*Statistik Stadt Zürich*). The dataset covers the years 1999–2022 and is originally retrieved by the tax office of the Canton Zurich. The year 2022 represents the most recent available year. For each statistical zone and year, the dataset contains separate rows for the basic and married tax rates. Each rate is documented by the first quartile, median and third quartile of taxable income (Table 3.10).

For this thesis, the median taxable income for the year 2022 was selected. The median was preferred over quartile due to its robustness against extreme values, which is especially relevant in Zurich given the presence of high-income households that could distort the comparison of statistical zones. The dataset does not include a median for all residents (married or unmarried) and only includes medians for the basic tax rate (applicable to unmarried individuals) and the married tax rate (applicable to married couples). Since married residents are most likely spatially clustered or life dependent on more factors than unmarried individuals, only the basic rate median income was used in this thesis. In further research, a combined measure for both married and unmarried residents would be more suitable and representative. A further limitation is the exclusion of one zone. The zone *Paradeplatz* was excluded from the analysis as income data were unavailable under both rates, as there are no residents in this zone.

Table 3.10: Extract of the income (in thousand Swiss francs) dataset from the city's statistical office.

Year	Zone ID	Zone Name	Tax Rate	Q1	Median	Q3
1999	5105	Ackerstrasse	Basic Rate	14.8	30.7	47.85
1999	5105	Ackerstrasse	Married Rate	28.5	48.3	64.1
1999	11503	Albin Zollinger-Platz	Basic Rate	19.4	39.4	59.1
1999	11503	Albin Zollinger-Platz	Married Rate	51.0	79.5	115.3

3.7.2 Nationality Composition

Like the income data, the nationality composition dataset was provided by the statistical office of the city upon special request and covers the years 1993-2024 for all statistical zones in Zurich. For each zone and year, the dataset records the number of non-Swiss and Swiss residents, the total population and the share of non-Swiss residents in percent (Table 3.11).

This thesis uses the share of non-Swiss residents per statistical zone of the year 2022 as the second socioeconomic predictor. This indicator serves as a proxy for socioeconomic vulnerability, as foreign nationals in Switzerland face structural challenges in accessing the labor market, affordable housing and social services (Ebner & Helbling, 2016; Zschirnt et al., 2025). In Zurich specifically, higher concentrations of non-Swiss residents are

consistently found in northern and western districts with lower socioeconomic conditions (**pluss_stadt_2024**). This makes the variable a meaningful indicator of neighborhood-level inequality in the local context.

Table 3.11: Extract of the nationality composition dataset from the city's statistical office.

Year	Zone ID	Zone Name	Non-Swiss	Swiss	Total	Non-Swiss (%)
1993	1101	Zähringerstrasse	176	408	584	30.1
1993	1102	Prediger	169	810	979	17.3
1993	1103	Grossmünster	186	699	885	21.0
1993	1104	Oberdorf	115	570	685	16.8

3.7.3 Age Distribution

High shares of children and elderly residents are among the most consistently used indicators of demographic vulnerability in the social vulnerability literature, reflecting their reduced capacity to cope with resource constraints independently (Mah et al., 2023; Wallace et al., 2015). Furthermore, they are the two age groups that have difficulty regulating rising heat which makes them more vulnerable to a changing urban climate (Campbell et al., 2018). Elderly residents also use and access parks differently than other age groups (Enssle & Kabisch, 2020; Poppe et al., 2022; Sugiyama et al., 2019).

Unlike the two previous socioeconomic variables, the age distribution data are publicly available at the statistical zone level on the website of the city's statistical office. However, as the website is structured by neighborhood rather than by topic, the relevant datasets had to be extracted individually for each neighborhood and subsequently merged into a single file using a Python script. The underlying dataset, titled "population number by age, gender and nationality"[2], provides population counts for each single year of age from 0 to 111 per statistical zone.

To derive meaningful indicators of socioeconomic vulnerability, the individual age values were aggregated into three groups: children and youth (0–15), working-age adults (16–64) and older adults (65+). The age thresholds follow the conventional boundaries of labor market participation in Switzerland, where compulsory schooling ends and vocational training typically begins around age 15 to 16, and statutory retirement age is set at 65 (Bundesamt für Statistik, 2026). For this thesis, the shares of the 0–15 and 65+ age groups for the year 2022 were selected as indicators of demographic vulnerability. Both groups fall outside the working-age population. They are therefore more likely to depend on public resources and services, including access to urban greenspace. Table 3.12 shows an extract of the final dataset.

[2]Original: "Bevölkerungsbestand nach Alter, Geschlecht und Herkunft"

Table 3.12: Extract of the age distribution dataset, showing population count per age group, derived from the city's statistical office.

Year	Zone ID	Zone Name	0-15	16-64	65+
1999	10101	Riedhof	505	1903	845
1999	10102	Hönggerberg	196	1486	791
1999	10103	Imbisbühlstrasse	249	1775	679
1999	10104	Werdinsel	204	1310	592

3.7.4 Descriptive Overview and Intercorrelations

Prior to regression modeling, the distributional properties and intercorrelation structure of the four predictors were examined. Shapiro–Wilk tests were applied to assess normality and both Pearson and Spearman correlations were computed to account for potential non-normality. Variance Inflation Factors (VIF) were inspected to assess multicollinearity prior to regression estimation. Descriptive statistics and correlation results are reported in Section 4.4.

3.8 Inequality Analysis

This thesis investigates whether park access and park characteristics are distributed equally across Zurich's statistical zones, which vary in their socioeconomic/demographic composition. The four socioeconomic and demographic variables (median income, share of foreign nationals, share of elderly residents (65+) and share of youth (0-15)) will be referred to as predictors in the following parts.

3.8.1 Analytical Approach

Both dimensions of this inequality analysis (park access and park characteristics) follow the same analytical sequence: a descriptive spatial overview, a bivariate correlation analysis and a confirmatory regression model with spatial diagnostics.

Descriptive Analysis

As a first step, outcome variables are mapped across statistical zones to identify broad spatial patterns. Descriptive statistics are reported for all analytical variables and boxplots as well as 100%-stacked-area-charts were constructed to show each outcome variable compared to the four predictors. Section A.8 explains in detail how the 100%-stacked-area-charts were computed.

Bivariate Correlation Analysis

Second, Spearman rank correlations between each outcome variable and each predictor are computed to provide a non-parametric overview of bivariate associations, given that several outcome variables exhibit skewed distributions across zones.

Regression Model

Third, an ordinary least squares (OLS) regression ("Introduction to Linear Regression Analysis," 2012) is estimated with all predictors entered simultaneously. Variance inflation factors (VIF) are inspected prior to estimation to assess multicollinearity among predictors. All continuous variables are standardized prior to estimation, so that coefficients are interpretable as standardized effect sizes.

Spatial Autocorrelation and Spatial Error Model

Last, Moran's I (Moran, 1950) is computed on the OLS residuals using a row-standardized Queen contiguity weights matrix (Cliff, A. D. & Ord, J. K., 1981) to test for residual spatial autocorrelation. Where Moran's I is statistically significant ($p < 0.05$), the Lagrange Multiplier (LM) test is used to select between a Spatial Lag Model (SLM) and a Spatial Error Model (SEM) (Anselin, 1992). The model with the higher significant LM statistic is preferred. SEM coefficients are estimated via maximum likelihood (*spreg.ML_Error*) and interpreted as the primary results, with OLS coefficients retained for compatibility with non-spatial literature.

The analysis is conducted on 211 statistical zones, excluding the four lake zones (*See Ost*, *See West*, *See Süd-West* and *See Nord*) and the Paradeplatz zone, which is excluded due to missing income data as it constitutes a purely commercial zone without registered residents. Spatial weights are constructed on the same 211-zone sample.

3.8.2 Park Distribution Inequality

The dependent variable in this analysis is the population-weighted park access score (Section 3.3). The model includes the four predictors (median income, share of foreign nationals, share of elderly residents and share of youth), operationalizing the inequality framework outlined in Section 2.4.

A negative coefficient for median household income indicates that zones with lower income have systematically lower park access. Meaning they show a distributional inequality. A positive coefficient for the share of foreign nationals would similarly indicate that zones with higher shares face lower park accessibility. For the demographic predictors, negative coefficients would suggest that zones with higher concentrations are disproportionately underserved. Again it would show distributional disparity.

The network-based forest access score per zone, computed in Section 3.5 is also investigated additionally. Zones with high forest accessibility may record lower park accessibility scores despite providing substantial greenspace. Ignoring this measure would risk conflating forest proximity with park deprivation. However, it is important to note that there are also other types of greenspace. And they are not specifically investigated in this thesis.

3.8.3 Park Characteristic Inequality

The dependent variables in this analysis are the five zone-level characteristics scores (vegetation cover, bench density, path density, fountain availability and public toilet availability, Section 3.4), each regressed separately on the same four predictors following the analytical approach described in Section 3.8.1. Results are presented separately for each outcome variable in Section 4.5.5.

Chapter 4

Results

The results outlined in this chapter build upon the methodological framework introduced in Chapter 3. The chapter follows the analytical sequence from spatial description to statistical inference. Section 4.1 first establishes where parks are located across the City of Zurich, presenting the final selection of 104 parks and their distribution across the districts and buffer zone. Section 4.2 then compares the three urban greenspace measures (park accessibility, forest accessibility and baseline greenness) highlighting how their spatial patterns diverge despite all three capturing urban greenery. In a next step, Section 4.3 shifts focus from access to characteristics, mapping the spatial distribution of the five park characteristics. Moving away from greenspace, Section 4.4 then describes the socioeconomic and demographic composition of Zurich's statistical zones, providing the predictor side of the subsequent inequality analysis. Finally, Section 4.5 brings together the greenspace measures with the four predictors, testing associations between greenspace accessibility, characteristics and low socioeconomic status through multiple statistical analyses.

4.1 Spatial Distribution of Parks

Figure 4.1 shows the spatial distribution of the 104 parks in Zurich (including the 2 km buffer) that were selected in Section 3.2. Parks are distributed unevenly across the city, with a notable concentration in the western and southern districts, especially in the zones close to the lake. Furthermore, comparatively fewer parks are located in the densely built central and northern areas. Several larger park polygons are situated at the urban periphery, while the city center is characterized by smaller, more dispersed parks. A complete list of all parks in the final dataset is provided in Section A.7.

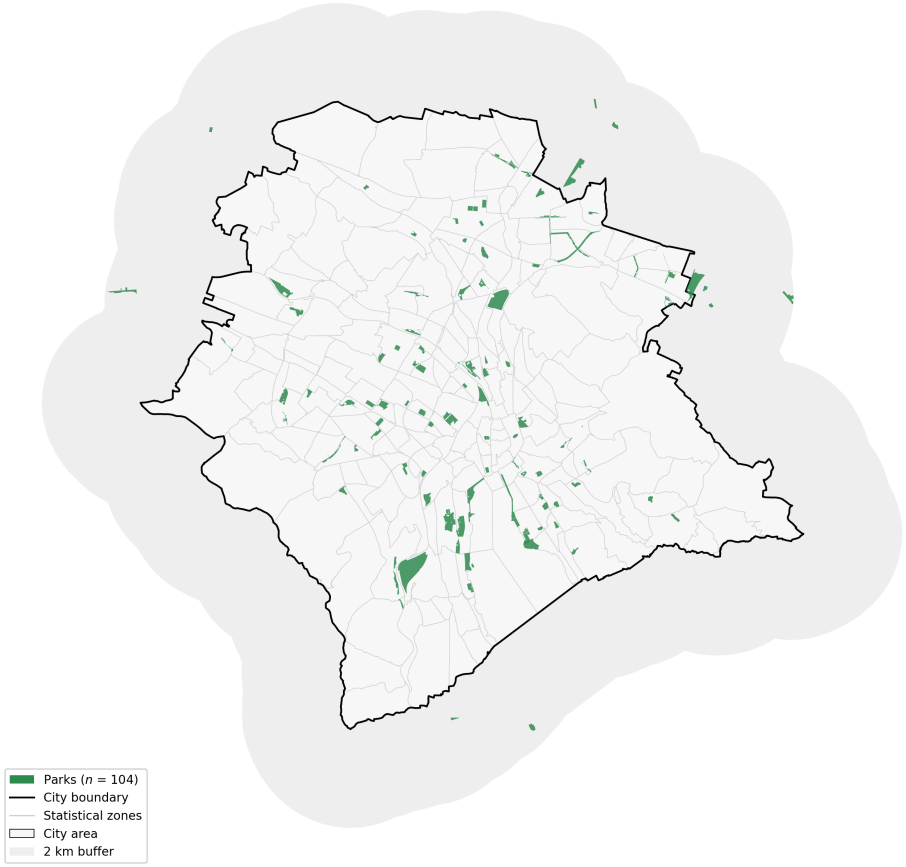


Figure 4.1: Final park selection in the city of Zurich and 2 km buffer zone ($n = 104$).

Table 4.1 summarizes the distribution of the 104 parks across Zurich's 12 city districts (*Stadtkreise*), with 11 parks located within the 2 km buffer zone outside the city boundary[1]. Park counts range from three parks in Kreis 10 (Höngg & Wipkingen) to twelve in Kreis 11 (Zürich-Nord). Total park area varies more substantially: Kreis 2 (Enge, Wollishofen & Leimbach) has the highest park area share (4.38%), driven by several large parks along the western lakeshore and the Uetliberg hillside. Districts 7 (Zürichberg, 0.57%) and 9 (Albisrieden, 0.59%) show the lowest shares despite their large district area. Overall, the distribution suggests spatial unevenness in both the number and size of parks across the city, which the subsequent accessibility analysis examines at the finer scale of statistical zones.

[1]Park counts were assigned based on park centroid location; nine parks whose boundaries extend across two districts were assigned the district containing their centroid. Park area was computed via geometric intersection with district boundaries, independent of centroid assignment.

Table 4.1: Number of parks and park area share per Stadtkreis, Zurich. Park counts are based on centroid assignment; park area is computed via geometric intersection with district boundaries.

Kreis	Parks (n)	Park Area (ha)	District Area (ha)	Park Area (%)
1	6	6.62	180.0	3.68
2	11	48.43	1106.6	4.38
3	8	12.57	865.1	1.45
4	6	10.14	290.6	3.49
5	6	6.46	199.7	3.24
6	8	20.05	510.1	3.93
7	8	8.57	1501.7	0.57
8	10	15.35	480.6	3.19
9	6	7.10	1205.7	0.59
10	3	7.68	908.6	0.85
11	12	14.06	1342.9	1.05
12	9	12.29	596.6	2.06
Outside city	11	24.19	–	–
Total	104	193.51	–	–

Parks spanning district boundaries ($n = 9$) were assigned to the district containing their centroid for count purposes; park area was computed via geometric intersection regardless of centroid assignment.

4.2 Urban Greenspace Patterns

This section presents and compares the three urban greenspace measures (park accessibility, forest accessibility and baseline greenness). Park and forest accessibility are based on the zone aggregation of population-weighted accessibility, while the baseline greenness depicts a share of vegetation cover per statistical zone. The baseline greenness measure represents all types of urban greenspace, while the two accessibility measures only portray one type of urban greenspace each.

4.2.1 Park Accessibility

Park accessibility scores range from 0 to 20.024 (mean = 4.115, SD = 3.243), with a right-skewed distribution (skewness = 1.563). This distribution indicates that a small number of zones experience a substantially higher park access than the majority. Figure 4.2 displays the park accessibility scores across statistical zones in the city. The scores exhibit strong positive spatial autocorrelation across Zurich's statistical zones. The Global Moran's I is 0.693 ($p = 0.001$) which indicates that zones with high park access tend to be surrounded by similarly high-access zones, while poorly served zones cluster together. This pattern is consistent with the spatial concentration of parks in specific districts observed in Figure 4.2 and confirms that park accessibility is not randomly distributed across the city.

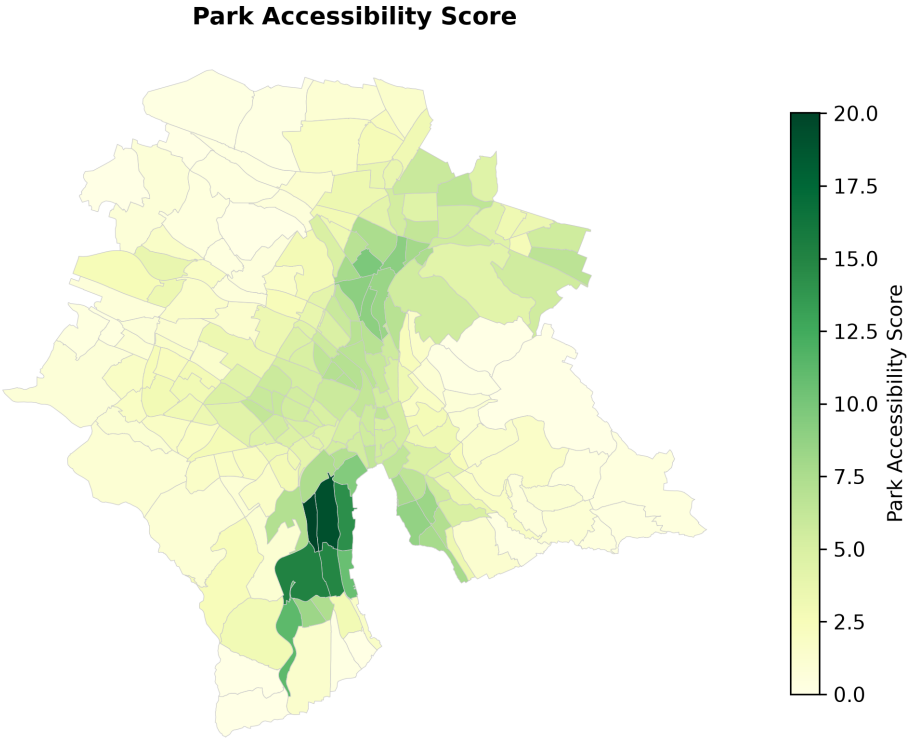


Figure 4.2: Map of park accessibility scores for all statistical zones in the city of Zurich.

4.2.2 Forest Accessibility

Forest accessibility scores are systematically lower than the park values (mean = 1.69, SD = 1.81), reflecting both the peripheral location of forest areas relative to the urban core and the applied area cap of 1.94 ha per forest area (75th percentile of the park area distribution). Figure 4.3 shows how the forest accessibility scores are distributed across the city's statistical zones. The Global Moran's I suggests that forest accessibility scores (Moran's $I = 0.765$, $p = 0.001$) are even more strongly clustered in space than the park accessibility scores. The higher Moran's I relative to park accessibility is expected: whereas parks are discrete, scattered features distributed across the built environment, forests form continuous landscape units concentrated in the northern, eastern and southern edges of the city.

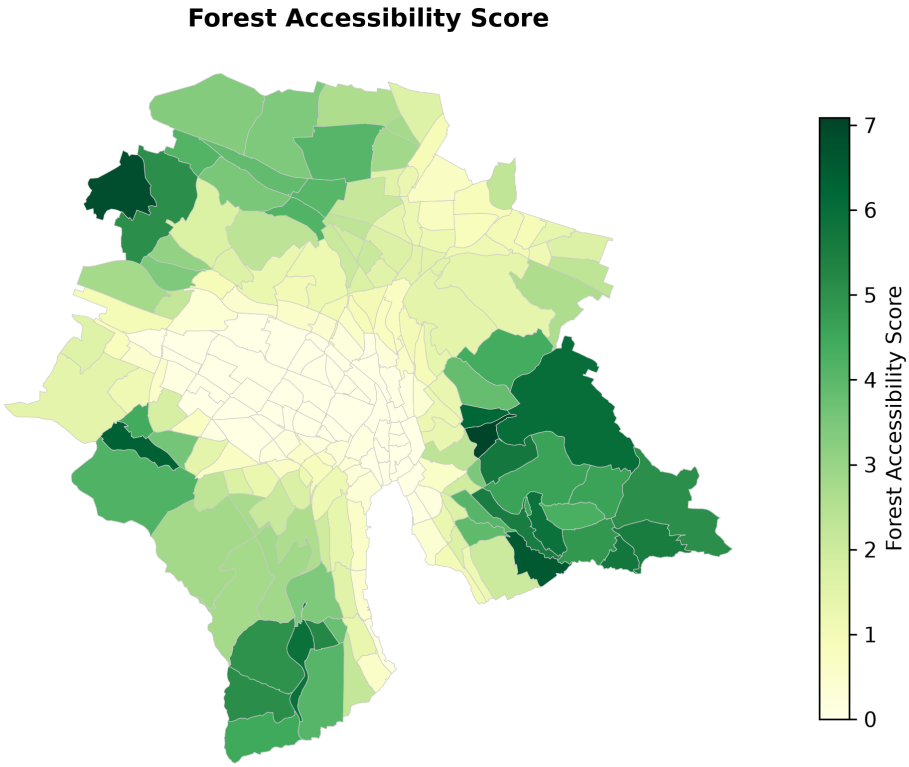


Figure 4.3: Map of forest accessibility scores for all statistical zones in the city of Zurich.

4.2.3 Baseline Greenness

Figure 4.4 shows another approach to a zonal greenness measurement. It examines all cells, only selects cells with a minimum of 0.3 (threshold for vegetation displayed by the NDVI) and calculates how many cells per statistical zone are considered as vegetation.

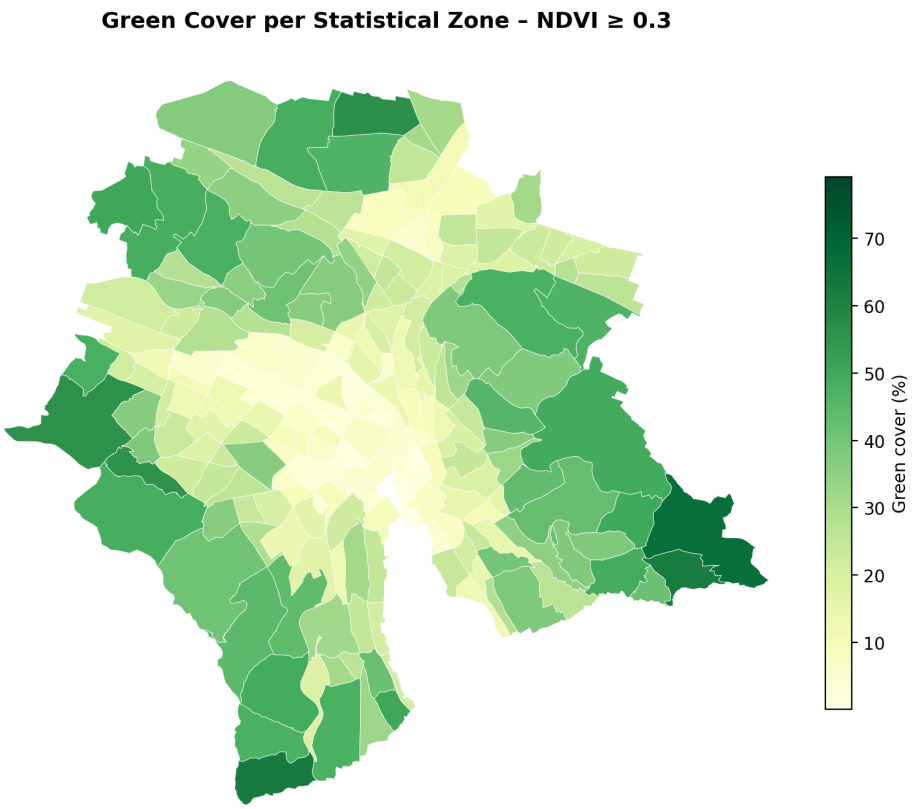


Figure 4.4: Map of the percent of vegetation cells with a threshold of 0.3 NDVI value (baseline greenness) for all statistical zones in the city of Zurich.

4.2.4 Comparison of Urban Greenspace Measures

To assess the degree of spatial overlap between the three greenspace measures, Spearman correlation coefficients were computed between park accessibility, forest accessibility and NDVI green cover / baseline greenness across all 212 statistical zones (Table 4.2)[2]. Forest accessibility and baseline greenness show a strong positive correlation ($\rho = 0.768$, $p < 0.001$). Park accessibility correlates negatively with both forest accessibility ($\rho = -0.456$, $p < 0.001$) and baseline greenness ($\rho = -0.563$, $p < 0.001$). Table 4.3 reports descriptive statistics for the population-weighted park and forest accessibility scores across the 212 statistical zones retained after excluding the four lake zones.

Comparing the map of park access (Figure 4.2) and the map of forest access (Figure 4.3) reveals contrasting spatial patterns between park and forest accessibility. Park scores are highest in the southern districts and decrease towards the northern and eastern periphery. Forest accessibility scores show an inverse pattern, with the highest values in the northern and eastern zones, and significantly lower scores in the inner-city zones.

[2]Note: Greenspace was measured over all 212 non-lake statistical zones. The socioeconomic and demographic predictors only contained 211 zones because one further zone did not contain data for median income.

Table 4.2: Spearman correlations between the three greenspace measures: park accessibility, forest accessibility and baseline greenness (n = 212).

	Park Accessibility	Forest Accessibility	NDVI Green Cover
Park Accessibility	1.000	-0.456^{***}	-0.563^{***}
Forest Accessibility	-0.456^{***}	1.000	0.768^{***}
NDVI Green Cover	-0.563^{***}	0.768^{***}	1.000

Note: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 4.3: Descriptive statistics of population-weighted park and forest accessibility scores across Zurich statistical zones ($n = 212$).

	Park Score	Forest Score
N	212	212
Mean	4.115	1.689
SD	3.243	1.764
Min	0.000	0.000
Q25	1.672	0.204
Median	3.565	1.205
Q75	5.775	2.415
Max	20.024	7.088
Skewness	1.563	1.157

Furthermore, Figure 4.5 portrays the difference between park score and forest score per statistical zone: With blue zones representing higher park access scores than forest scores, white zones have similar access scores and red zones exhibit higher forest scores than park scores. The figure clearly shows that inner-city zones tend to have higher park accessibility than forest accessibility, while peripheral zones tend to have higher forest access than park access.

Taken together, the contrasting spatial patterns of park and forest accessibility, with parks concentrated in central and southern zones, forests in peripheral zones, are further confirmed by their respective spatial autocorrelation statistics. Both scores exhibit strong positive spatial clustering (park: Moran's $I = 0.693$, $p = 0.001$; forest: Moran's $I = 0.765$, $p = 0.001$), indicating that neither greenspace type is randomly distributed across the city.

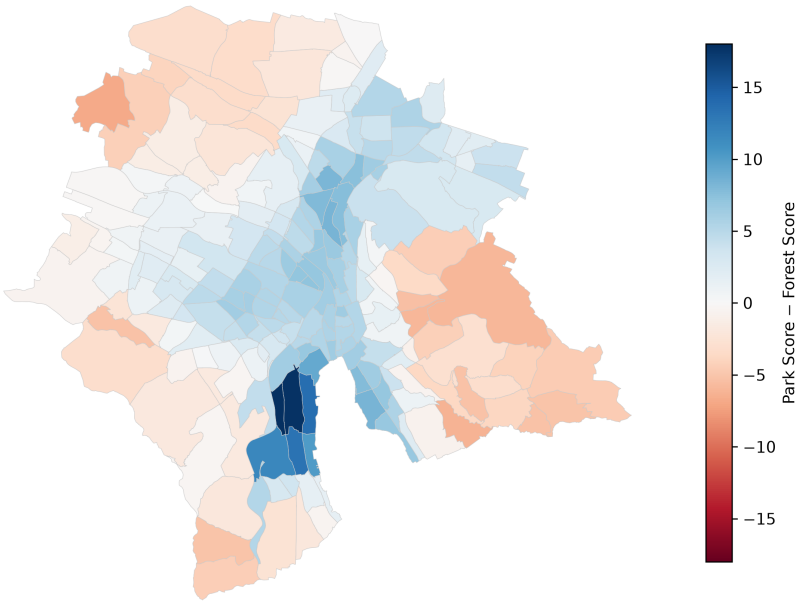


Figure 4.5: Difference of park accessibility scores and forest accessibility scores across Zurich's statistical zones. Blue zones have higher park accessibility values than forest accessibility and red zones display higher forest scores than park scores.

4.3 Spatial Distribution of Park Characteristics

Table 4.4 and Figure 4.6 present descriptive statistics for the five population-weighted park characteristics scores across the 212 residential statistical zones of Zurich. Each score reflects the decay-weighted mean characteristic value of parks reachable within a maximum of 1'200 m network distance, aggregated to the zone level using building-level population counts. Four zones (Mahrbachweg, Sihlweidstrasse, Zoo and Rütihof) record a score of zero across most characteristics, indicating the absence of any reachable park within the network distance threshold. These zones are retained in the dataset, consistent with the treatment of the park accessibility score. The distributions, shown in Figure 4.6, are discussed individually in the following subsections.

Table 4.4: Descriptive statistics of population-weighted park characteristic scores across Zurich statistical zones ($n = 212$). Scores represent the decay-weighted mean characteristic value of parks reachable within 1'200 m network distance.

	vegetation score	path score	bench score	toilet score	fountain score
N	212.0	212.0	212.0	212.0	212.0
Mean	62.9525	635.7253	0.0021	0.4144	0.7498
SD	18.09	251.7278	0.0011	0.2667	0.2725
Min	0.0	0.0	0.0	0.0	0.0
Q25	53.8566	471.0565	0.0014	0.2039	0.6750
Median	64.4899	638.2475	0.002	0.4248	0.8266
Q75	73.9781	769.5467	0.0028	0.6039	0.9512
Max	96.9651	1196.6479	0.005	0.9997	1.0
Skewness	-1.096	-0.0838	0.2333	0.0553	-1.4529

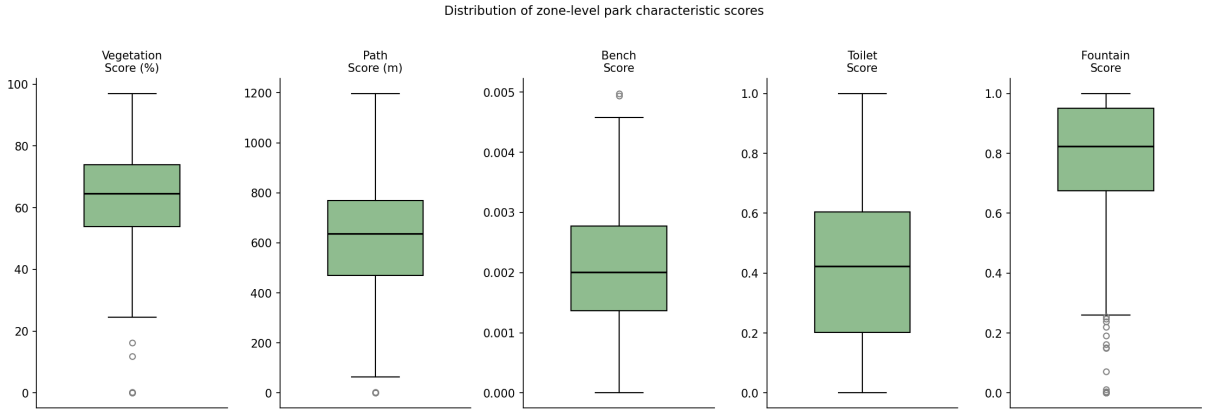


Figure 4.6: Distribution of zone-level park characteristic scores (bench density, fountain availability, toilet availability, vegetation cover and path density) across all statistical zones in Zurich ($n = 212$).

4.3.1 Vegetation Cover

Vegetation cover scores display a moderate left skew (−1.10), with a mean of 62.95 % and a median of 64.49 % indicating that most zones have access to parks with above-average vegetation cover. The interquartile range spans from 53.86 % to 73.98 %, reflecting meaningful variation in the greenness of reachable parks across the city. Spatially, higher scores are found in the western and southwestern districts, as well as in parts of the city with access to larger, more vegetated parks. Lower values appear in some central and eastern zones where the reachable park network includes more built-up or paved park areas. Four zones record a score of zero (see Figure 4.7).

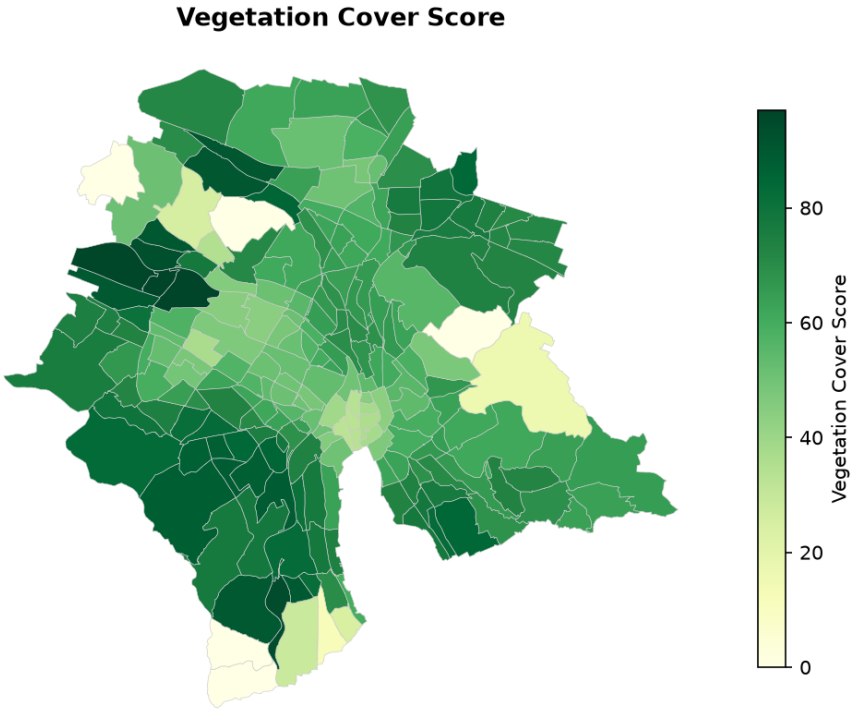


Figure 4.7: Map of zonal-aggregated vegetation cover scores of urban parks.

4.3.2 Path Density

The path density score is the most variable characteristic in absolute terms (mean = 635.73 $\mathrm{m\,m^{-2}}$, $SD = 251.73$), though its near-zero skewness (−0.08) indicates a broadly symmetric distribution across zones. The interquartile range (471.06–769.55) reflects substantial differences in the path infrastructure of reachable parks. Spatially, higher path density scores are concentrated in the northwestern districts and parts of the inner city, while lower values appear in the east and some peripheral zones. Four zones record a score of zero (see Figure 4.8).

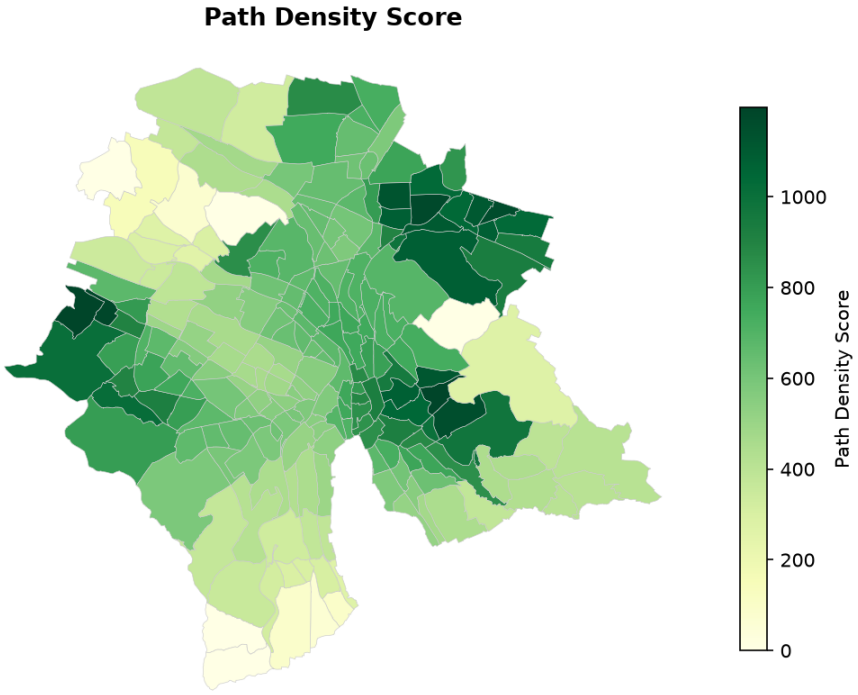


Figure 4.8: Map of zonal-aggregated park path density scores of urban parks.

4.3.3 Bench Density

The bench density score exhibits moderate variation across zones (mean = 0.0021 benches $\mathrm{m^{-2}}$, $SD = 0.0011$), with a slight positive skew (0.23) indicating a small number of zones with higher bench provision. Spatially, higher scores are concentrated in the inner-city districts and parts of the western city, where the park network is denser and individual parks are better equipped. Peripheral zones in the north and northwest display markedly lower values. Four zones record a score of zero due to the absence of reachable parks (see Figure 4.9).

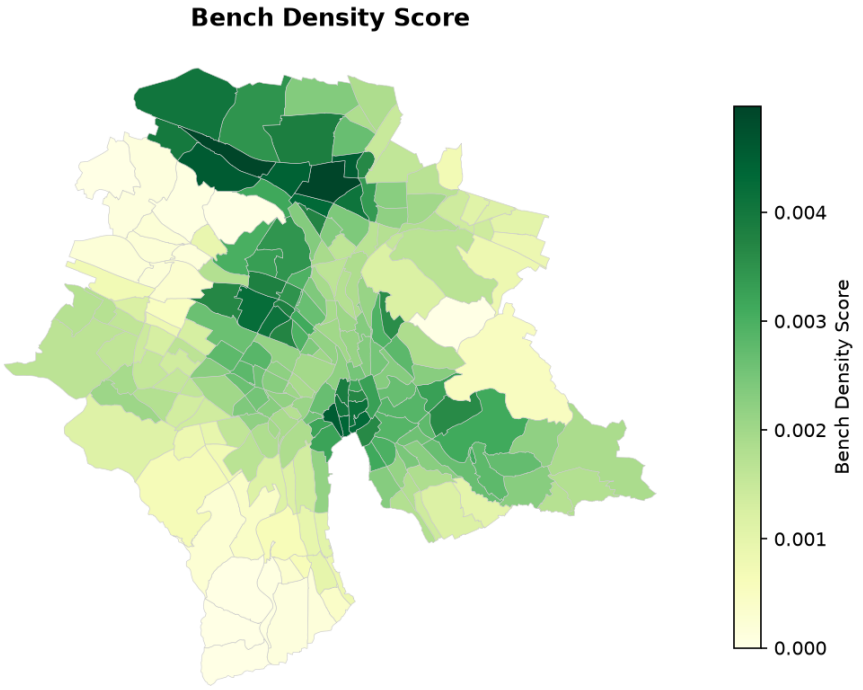


Figure 4.9: Map of zonal-aggregated bench density scores of urban parks.

4.3.4 Public Toilet Availability

The toilet availability score is the most evenly distributed of the five characteristics, with a near-symmetric distribution (skewness = 0.06), a mean of 0.41 and a median of 0.42. The interquartile range (0.20–0.60) reflects substantial variation across zones in the share of reachable parks providing toilet facilities. Nineteen zones record a score of zero which is by far the highest count among all characteristics. Many peripheral zones in district 11 (Mühlacker, Holzerhurd, Reckenhold, Lerchenberg, Zehntenplatz, Köschenrüti) and district 9 (Dunkelhölzli, Juchhof, In den Rütenen), as well as zones dominated by green or institutional land uses such as Uetliberg, Dolder and ETH Hönggerberg are among the zones with scores of zero. Spatially, Figure 4.10 shows no pronounced core–periphery gradient; instead, zones with low scores are dispersed across the city, suggesting that toilet provision varies primarily at the park level rather than following a systematic spatial pattern.

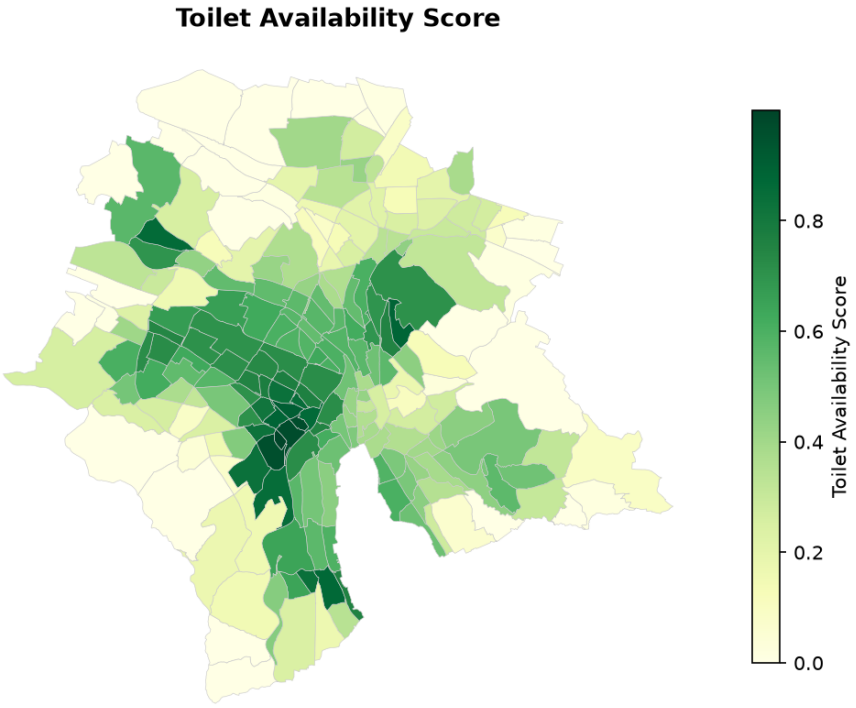


Figure 4.10: Map of zonal-aggregated public toilet availability scores of urban parks.

4.3.5 Fountain Availability

Fountain density scores show the strongest left skew among the five characteristics (-1.45), with a median of 0.83 and a 75th percentile of 0.95, indicating that the large majority of zones have access to parks with relatively high fountain density. The mean score of 0.75 ($SD = 0.27$) reflects this ceiling effect, with low values concentrated in a small number of peripheral zones. Spatially, Figure 4.11 reveals a distinct core-periphery gradient, with central and inner districts achieving near-maximum scores while outer zones, particularly in the northwest and far north, fall substantially below the city-wide median. Nine zones record a score of zero, suggesting that fountain provision is more spatially uneven at the park level than other attributes.

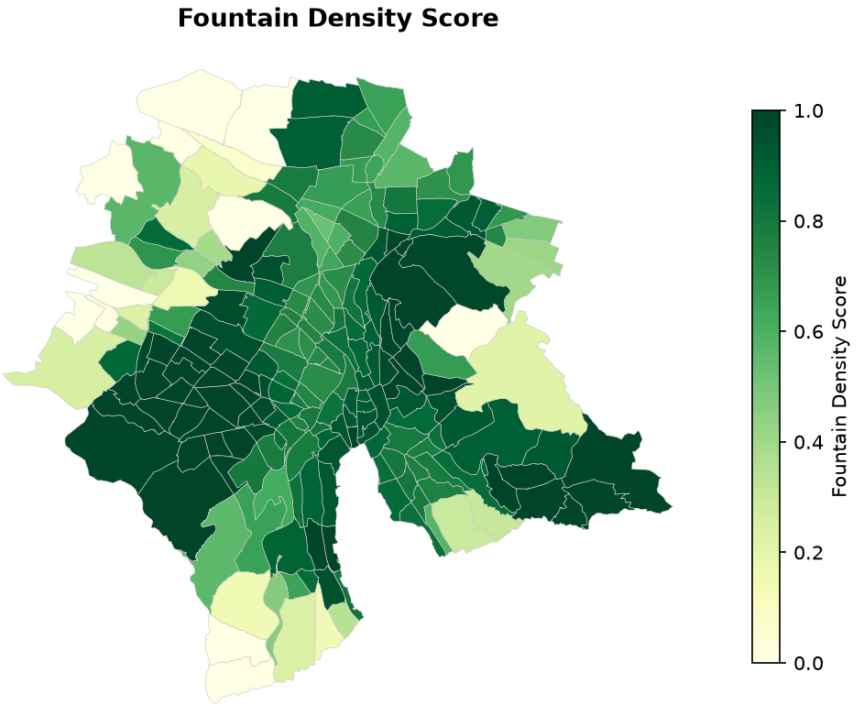


Figure 4.11: Map of zonal-aggregated fountain availability scores of urban parks.

4.4 Socioeconomic & Demographic Patterns

4.4.1 Spatial Patterns of Variables

Figure 4.12 shows maps of the distribution of the four socioeconomic and demographic predictors (median income, share of foreign nationals, share of elderly residents (65+) and share of youth (0–15)). These maps serve the main purpose to give an overview over the distribution of the four predictors across statistical zones of Zurich. One zone stands out in all four maps: ETH Hönggerberg displays a low median income, share of elderly and youth, while depicting a high share of foreign nationals. This is reasonable based on the assumption that mostly foreign national students live there on campus and most certainly do not have a high taxable income.

Global Moran's I statistics confirm that all four variables exhibit statistically significant positive spatial autocorrelation across Zurich's statistical zones (all $p = 0.001$, based on 999 permutations under a randomization assumption). Youth share displays the strongest clustering ($I = 0.510$), followed by elderly share ($I = 0.304$), median income ($I = 0.269$) and foreign national share ($I = 0.258$). These results indicate that similar values tend to cluster spatially rather than being distributed randomly across the city, motivating the use of spatial econometric methods in the inequality analysis presented in Section 4.5.1.

Local Moran's I (LISA) maps reveal distinct geographic patterns for each variable (Figure 4.13). High-income clusters (High–High) are concentrated in the lakeside districts

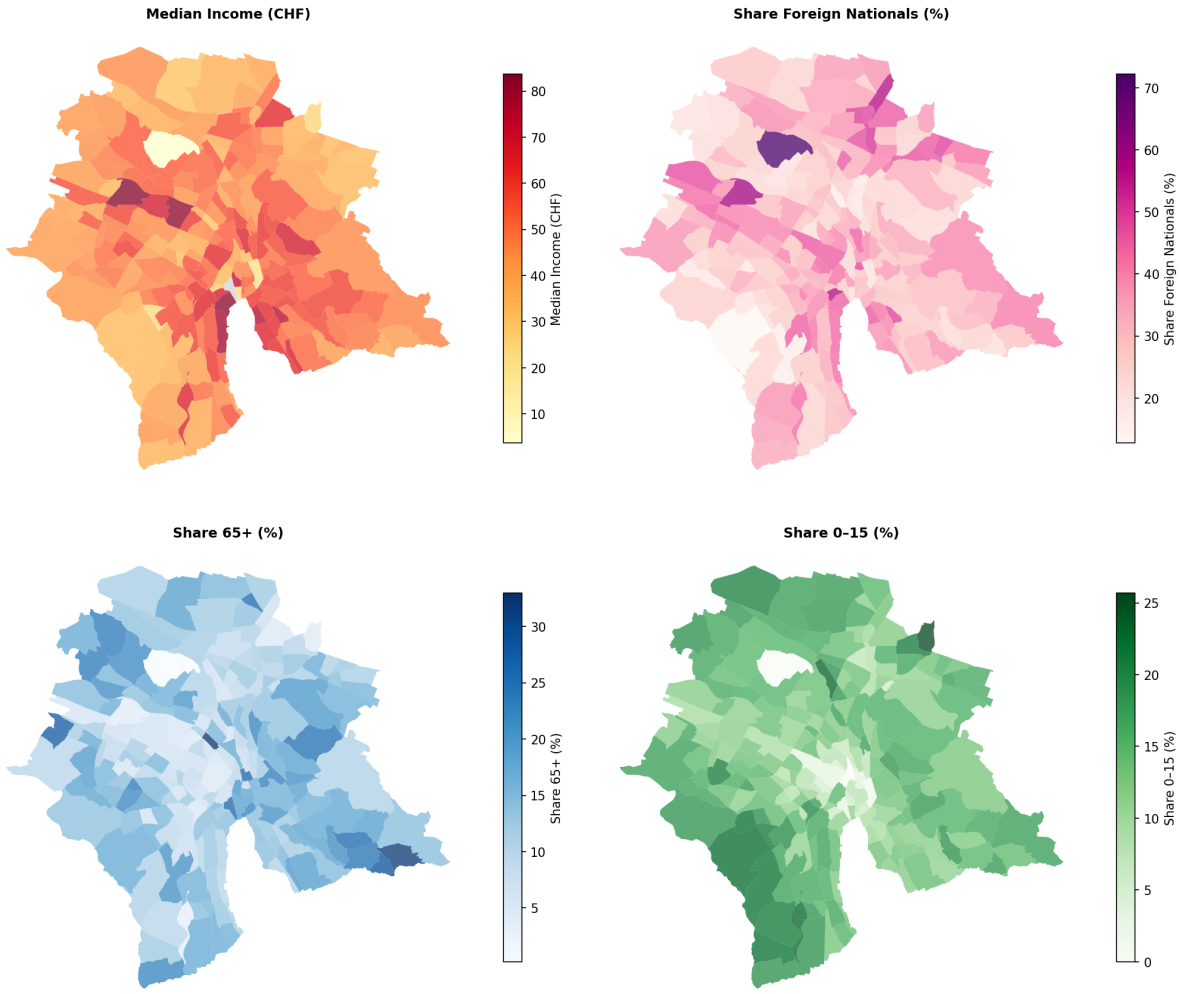


Figure 4.12: Maps of the four socioeconomic and demographic predictors: median income, share of foreign nationals, share of elderly residents (65+) and share of youth (0–15). Spatial units are the statistical zones of the City of Zurich.

to the west of the city center and in elevated zones to the east, consistent with Zurich's historically established affluent neighborhoods. Low-income clusters (Low–Low) appear predominantly in the western and south-western industrial zones. The spatial pattern of foreign national share is broadly inverse: high-concentration clusters are located in the northern and north-eastern parts of the city, while low-concentration clusters largely coincide with the high-income zones. Elderly share displays a more dispersed pattern, with notable High–High clusters in southern lakeside zones. The most spatially coherent pattern is observed for youth share, where contiguous High–High cluster spans several zones in the southern periphery, alongside a Low–Low cluster concentrated in the inner city.

The Getis-Ord G_i^* hot spot analysis largely corroborated these findings while providing additional gradation by confidence level (Figure 4.14). Income hot spots significant at 99% level align closely with the LISA High–High zones and cold spots at the same confidence

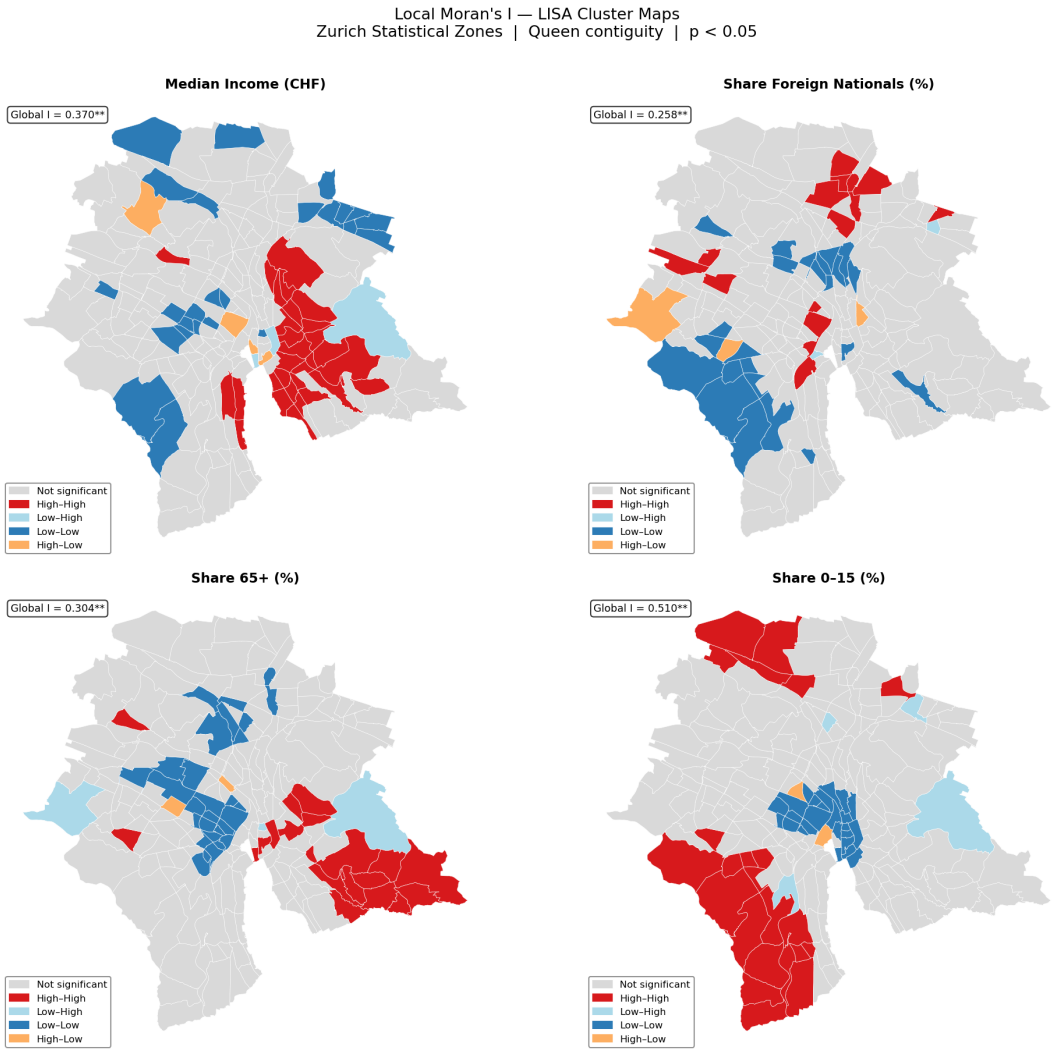


Figure 4.13: Local Moran's I (LISA) cluster maps for four socioeconomic variables across Zurich's 211 residential statistical zones (2022). Clusters are identified at $p < 0.05$ based on 999 permutations under Queen contiguity. High–High and Low–Low clusters indicate spatial concentration of similar values; High–Low and Low–High indicate spatial outliers.

level correspond to the western low-income cluster. The G_i^* results for youth share are particularly pronounced: a spatially extensive hot spot in the southern periphery reaches the 99% confidence threshold, reinforcing the LISA findings. For foreign national share, hot spots are concentrated in the north-east, while cold spots extend across the south-western and lakeside zones.

Taken together, these spatial patterns indicate that socioeconomic and demographic characteristics are not randomly distributed across Zurich but follow structured geographic gradients. The presence of significant spatial autocorrelation in the predictor variables themselves and not only in regression residuals further underscores the appropriateness of the Spatial Error Model applied in Section 4.5.1.

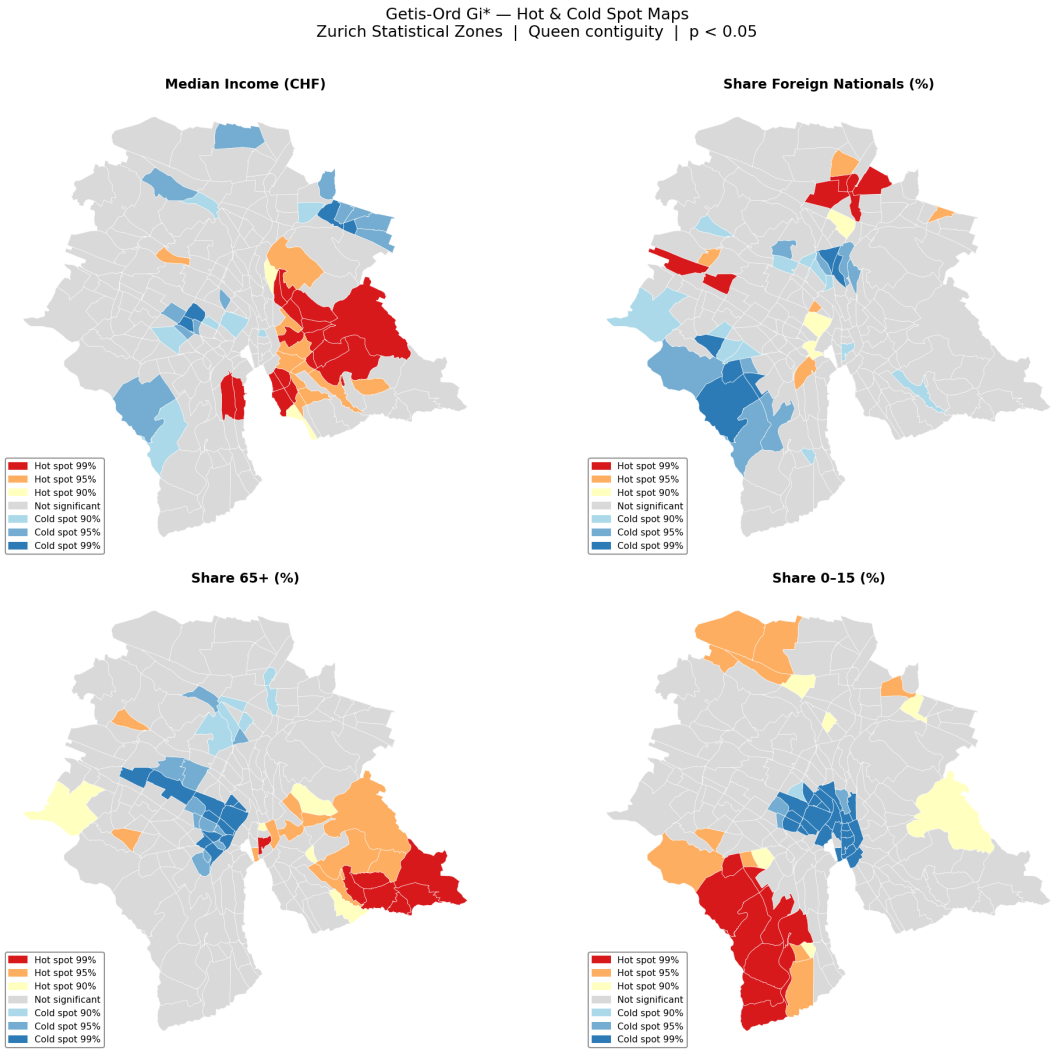


Figure 4.14: Getis-Ord G_i^* hot and cold spot maps for four socioeconomic variables across Zurich's 211 residential statistical zones (2022). Confidence levels of 90%, 95%, and 99% are distinguished. Queen contiguity weights with binary transformation were applied.

4.4.2 Intercorrelations

Table 4.5 reports descriptive statistics for the four socioeconomic and demographic predictors across the 211 statistical zones retained after excluding lake zones and zones with missing income data. Median income is moderately right-skewed (skewness = 0.62), reflecting a small number of high-income zones in the urban periphery, while the age structure variables distribution is more symmetrical. All four variables departed significantly from normality according to Shapiro–Wilk tests (all $p < 0.05$), motivating the use of both Pearson and Spearman correlations in the examination of pairwise predictor relationships.

Table 4.5: Descriptive statistics of zone-level socioeconomic and demographic characteristics ($n = 211$).

	Mean	SD	Min	Max	Skewness
Median Income (CHF 1,000)	66.13	19.57	3.70	140.09	0.62
Share Foreign Nationals (%)	33.34	8.93	12.79	72.20	0.66
Share 65+ (%)	13.97	5.62	0.22	32.98	0.55
Share 0–15 (%)	13.71	4.44	0.00	25.69	-0.38

Note. Statistics computed across 211 statistical zones (Statistische Zonen) of the City of Zurich. One zone (Paradeplatz) was excluded due to missing income data. All variables refer to the reference year 2022. Skewness values above |0.5| indicate moderate asymmetry.

Table 4.6 shows the pairwise correlations between predictors. Contrary to what might be expected, median income shows no significant correlation with any of the three remaining predictors (all $|r| \leq 0.11$, $p > 0.05$). This may reflect the heterogeneous income composition of statistical zones, where high- and low-income households co-exist within small spatial units, attenuating zone-level correlations that would otherwise be expected at broader scales.

Table 4.6: Bivariate Pearson (upper triangle) and Spearman (lower triangle) correlations among zone-level socioeconomic and demographic characteristics ($n = 211$).

	Income	Foreign	Elderly	Youth
Income	—	0.029	0.109	0.073
Foreign	0.020	—	-0.508***	-0.427***
Elderly	0.106	-0.521***	—	0.160*
Youth	-0.014	-0.430***	0.214**	—

Note. Upper triangle: Pearson r; lower triangle: Spearman ρ. Significance levels: * $p < .05$, ** $p < .01$, *** $p < .001$. $n = 211$ statistical zones; one zone (Paradeplatz) excluded due to missing income data.

The strongest intercorrelations are observed between share of foreign nationals and the two age variables: zones with higher shares of non-Swiss residents tend to have lower shares of elderly residents ($r = -0.508$, $\rho = -0.521$, $p < 0.001$) and lower shares of youth ($r = -0.427$, $\rho = -0.430$, $p < 0.001$). The negative association between foreign share and elderly share reflects distinct settlement geographies of established and immigrant populations within the city. The negative association with youth share is less intuitive and warrants careful interpretation in the regression results. Elderly and youth shares show a weak positive Pearson correlation ($r = 0.160$, $p = 0.05$; $\rho = 0.214$, $p < 0.01$), suggesting only a modest tendency for zones with older populations to also contain more children.

Overall, the moderate intercorrelations among predictors do not indicate severe multicollinearity. Variance Inflation Factors (VIF) confirmed this assessment, with all VIF values below 5 (Income: 1.034, Foreign: 1.643, Elderly: 1.387, Youth: 1.243), well within acceptable thresholds.

4.5 Inequality Analysis

4.5.1 Park Accessibility Inequality

Descriptive Analysis

With the consideration of the boxplots in Figure 4.15, park access scores above 11.96 were excluded in the 100%-Stacked-Area-Charts (Figure 4.16) to ensure outliers do not distort the visualization. Outliers were identified separately for the x-axis variable (park access score) and each socioeconomic and demographic variable using *Tukey's 1.5XIQR* rule (Dodge, 2010). Zones exceeding these thresholds were excluded from the respective panel prior to quartile binning. The boxplots in Figure 4.15 further indicate that several zones across all socioeconomic and demographic quartiles exhibit park access scores well above the inter-quartile range (e.g. reaching values of 15–20). The spread (inter-quartile range) of park access scores appears broadly comparable across quartiles, suggesting that within-quartile variability does not differ strongly by socioeconomic and demographic group.

Table 4.7 shows how quartiles were binned for reference.

Table 4.7: Quartile boundaries for the four socioeconomic and demographic variables, applicable to both the park and forest access 100%-stacked-area diagrams (Figure 4.16, Figure 4.18).

Variable	Min	Q1/Q2	Q2/Q3	Q3/Q4	Max
Median Income (CHF)	28'600	49'600	56'300	67'200	95'400
Share Foreign Nationals (%)	12.8	26.6	32.4	39.1	56.8
Share Elderly 65+ (%)	0.2	9.9	13.5	17.1	28.2
Share Youth 0–15 (%)	3.9	11.6	14.1	16.7	23.5

Note. Boundaries shown after Tukey 1.5×IQR outlier exclusion per variable (see Figure 4.16 for excluded n per panel). Boundaries are identical across the park and forest access 100%-stacked-area diagrams, as quartile binning for each predictor is computed independently of the greenspace outcome.

Figure 4.16 shows the distribution of the four socioeconomic and demographic variables across the park access score, with each panel based on a variable-specific sample after outlier exclusion ($n = 203 - 209$).

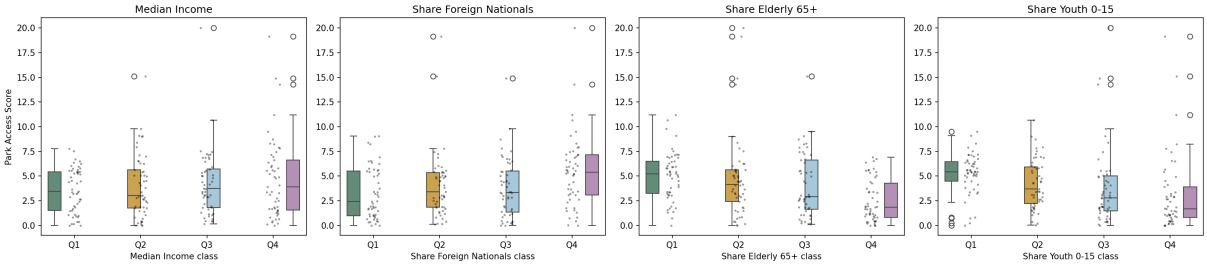


Figure 4.15: Box plots of park access scores by the four socioeconomic & demographic variables in quartiles.

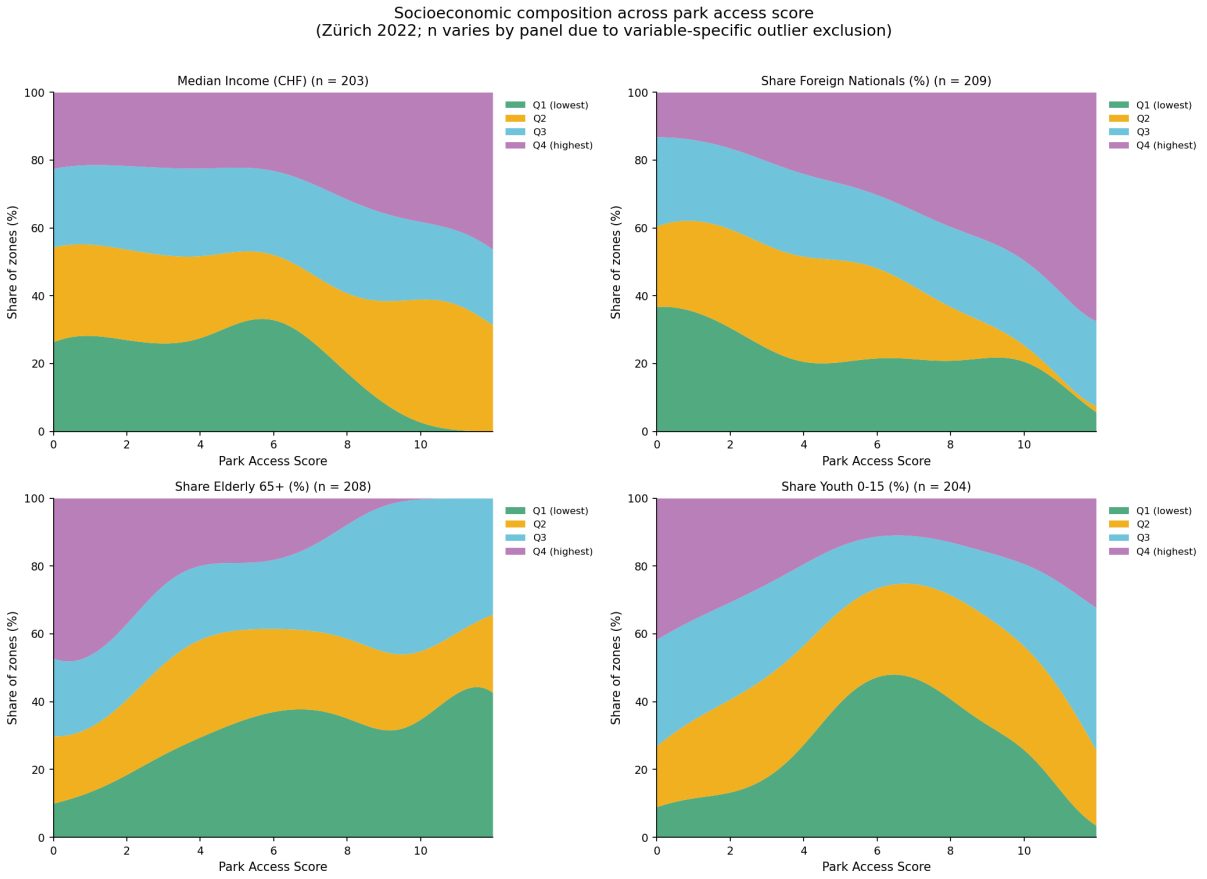


Figure 4.16: 100%-Stacked-Area-Charts for park access scores and the four variables: median income, share of foreign nationals, share of elderly (+65) and share of youth (0-15). The x-axis is truncated at a park access score of 11.96 (upper Tukey fence) to exclude outlying zones from the display (see panel titles for number of zones).

For median income, the four quartiles are distributed comparatively evenly across the park access score range. The lowest income-quartile (Q1) accounts for roughly 25-30% of zones up to a score of around 6, after which its share declines. The highest-income quartile (Q4) becomes increasingly dominant toward the upper end of the score range, exceeding 40% of zones beyond a score of 8.

The share of foreign nationals shows a similar distribution as the median income with a bit more of a downfall towards the upper end of the park score range. The lowest-share

quartile (Q1) accounts for around 35% of zones at a low park access score but declines steadily to below 10% among zones with the highest scores. The highest-share quartile (Q4) becomes increasingly dominant, exceeding 60% of zones at the upper end of the distribution.

The share of elderly residents (65+) displays the inverse pattern: the lowest-share quartile (Q1) increases from around 10% of zones at low park access scores to over 40% at high scores, while the highest-share quartile (Q4) declines from over 45% to below 15% over the same range. That means, generally speaking, zones with a lower share of elderly residents have higher park access scores and zones with higher shares display lower park scores.

The distribution of share of youth (0–15) is the most different of all four variables distributions: It shows a non-monotonic pattern with the lowest-share quartile (Q1) staying comparatively small at both ends of the park access score range (around 10–15%) but peaking at nearly 50% for zones with intermediate scores (around 6), before declining again toward the highest scores.

Bivariate Spatial Cluster Analysis

Bivariate Local Moran's I statistics were computed between the park access score and each of the four socioeconomic and demographic variables, using row-standardized Queen contiguity weights and 999 conditional permutations to assess statistical significance ($p < 0.05$). Table 4.8 summarizes the number of zones assigned to each cluster type per variable and Figure 4.17 maps their spatial distribution.

Table 4.8: Global bivariate Moran's I and local cluster classification for park access score against socioeconomic and demographic variables.

			Cluster classification, n (%)				
Variable	I_{BV}	p_{sim}	High-High	Low-High	Low-Low	High-Low	Not sig.
Median Income	0.080	.053	17 (8.1)	10 (4.7)	**30 (14.2)**	22 (10.4)	132 (62.6)
Share Foreign Nationals	0.138**	.001	16 (7.6)	11 (5.2)	33 (15.6)	**19 (9.0)**	132 (62.6)
Share Elderly 65+	−0.201**	.001	10 (4.7)	17 (8.1)	16 (7.6)	**36 (17.1)**	132 (62.6)
Share Youth 0–15	−0.186**	.002	14 (6.6)	13 (6.2)	12 (5.7)	**40 (19.0)**	132 (62.6)

Note. $n = 211$ for all variables. Spatial weights: row-standardised Queen contiguity. Statistical significance assessed via 999 conditional permutations. Bold values indicate the cluster type interpreted as the primary spatial deprivation indicator: Low-Low for median income (low income surrounded by low park access); High-Low for share of foreign nationals, share of elderly, and share of youth (high share surrounded by low park access).

** $p \leq .01$.

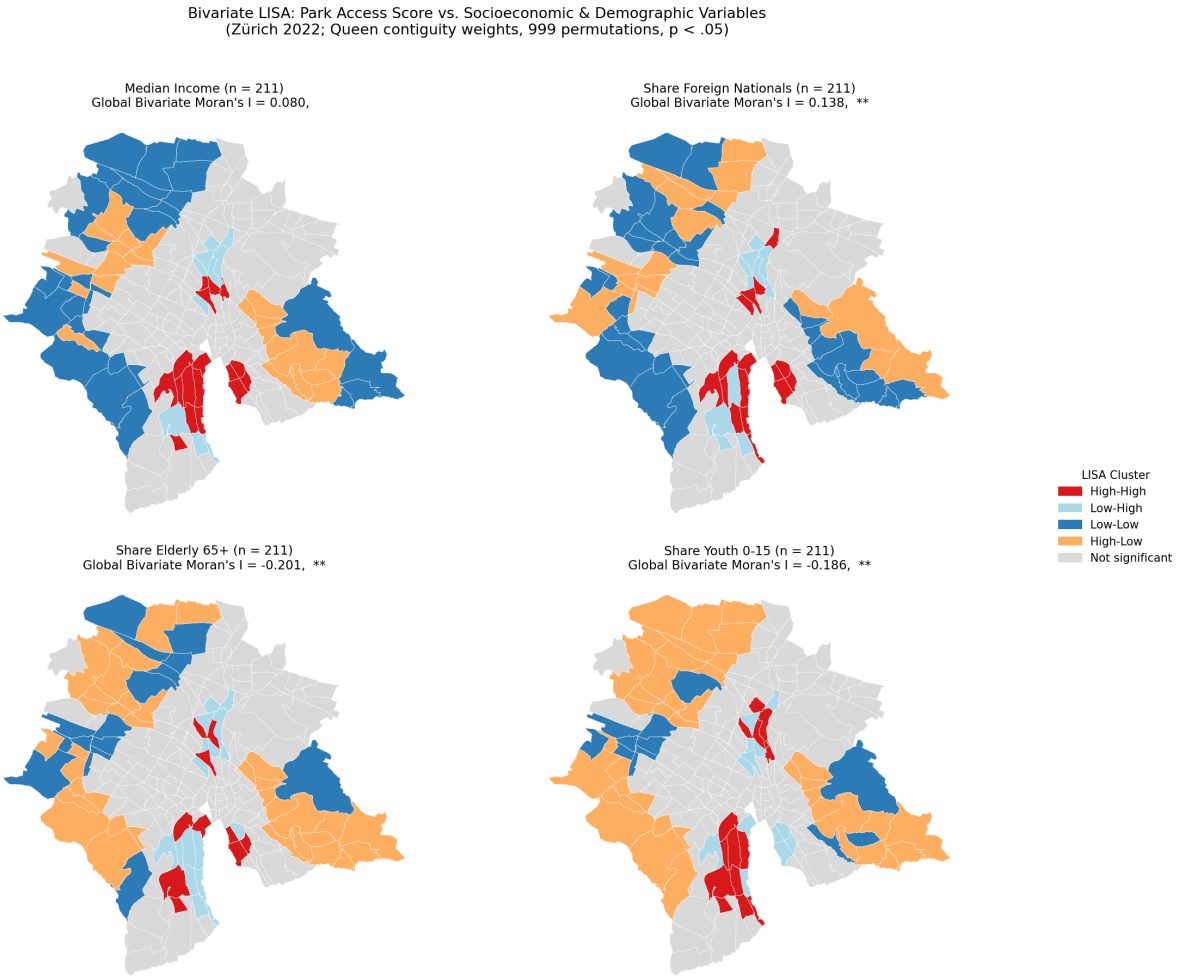


Figure 4.17: Bivariate Local Moran's I (LISA) cluster maps of the park access score against the four socioeconomic and demographic variables: median income, share of foreign nationals, share of elderly residents (65+), and share of youth (0–15).

Regression Analysis

Table 4.9 presents the OLS and SEM regression results for the park accessibility score with the four predictors entered as standardized predictors. The OLS model explains a modest share of the variance in park access scores ($R^2 = 0.125$, adjusted $R^2 = 0.108$). Median income is positively associated with the park access score ($\beta = 0.159$, $p = 0.019$), while share of elderly residents ($\beta = -0.238$, $p = 0.002$) and share of youth ($\beta = -0.175$, $p = 0.016$) are negatively associated. The coefficient for share of foreign nationals is not statistically significant ($\beta = -0.056$, $p = 0.501$). Variance inflation factors range from 1.06 to 1.63 across predictors, bringing up no multicollinearity concern.

Moran's I on the OLS residuals is 0.629 ($p = 0.001$, based on 999 permutations) which indicates that substantial positive spatial autocorrelation is present among the residuals.

The SEM yields a high and statistically significant spatial autoregressive parameter ($\lambda = 0.939$, $z = 43.36$, $p < 0.001$). The SEM also improves overall model fit relative to

the non-spatial specification ($AIC = 344.7$ versus 580.6 for OLS). This confirms that the spatial specification is preferred on both statistical and fit-based grounds. After accounting for spatial autocorrelation, none of the four predictors remain statistically significant at the $p < 0.05$ threshold: median income ($\beta = 0.038$, $p = 0.307$), share of foreign nationals ($\beta = -0.023$, $p = 0.644$), share of elderly residents ($\beta = -0.083$, $p = 0.064$) and share of youth ($\beta = -0.011$, $p = 0.835$).

Table 4.9: OLS and Spatial Error Model (SEM) results for the park access score.

	OLS		SEM	
Predictor	β (SE)	p	β (z)	p
Median income	0.159 (0.067)	0.019*	0.038 (1.02)	0.307
Foreign nationals (%)	-0.056 (0.083)	0.501	-0.023 (-0.46)	0.644
Elderly 65+ (%)	-0.238 (0.076)	0.002**	-0.083 (-1.85)	0.064
Youth 0–15 (%)	-0.175 (0.072)	0.016*	-0.011 (-0.21)	0.835

Note. $n = 211$. OLS: $R^2 = 0.125$, adjusted $R^2 = 0.108$, AIC = 580.6. VIF range 1.06–1.63. Moran's I on OLS residuals = 0.629 ($p = 0.001$). SEM (ML_Error): $\lambda = 0.939$ ($z = 43.36$, $p < 0.001$), pseudo-$R^2 = 0.102$, $AIC = 344.7$.
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

4.5.2 Forest Accessibility Inequality

Similar to the considerations taken for the park access score and its outliers, the 100%-Stacked-Area-Charts for the forest access score were cut off excluding outliers above a forest score of 5.92 in Figure 4.18. The figure shows the distribution of the four socioeconomic and demographic predictors across the forest accessibility score, with each panel based on a variable-specific sample after outlier exclusion ($n = 203$–209).

The forest charts show a very different picture than the park charts (Figure 4.16). For median income, the distribution is non-monotonic: the lowest-income quartile (Q1) increases from around 25% of zones at the lowest forest access scores to a peak of nearly 40% around a score of 3, before declining sharply toward the upper end of the range. The highest-income quartile (Q4) remains comparatively small with around 20–25% across most of the range but increases markedly beyond a score of 4, exceeding 40% at the highest score. It is also noticeable that the lowest-income quartile is not represented by the highest forest score of 6.

The share of foreign nationals shows a pattern that is essentially inverse to its relationship with the park access score: the lowest-share quartile (Q1) increases steadily from around 20% of zones at low forest scores to over 40% at the highest scores, while the highest-share quartile (Q4) declines from around 30% to near zero over the same range. This is consistent with the pattern of parks being located in the center and forests in the

periphery established in the greenspace comparison (Section 4.2.4). Zones with a high share of foreign nationals tend to be located centrally (Section 4.4).

Similarly to the share of foreign nationals, the share of elderly residents displays a pattern inverse to the distribution of the park access score. The lowest-share quartile (Q1) accounts for the largest share of zones at low forest scores (over 40%), declining to zero at a score of 4 and only showing up insignificantly at a score of 5 and above. Meanwhile the highest-share quartile (Q4) increases with rising forest access scores. At the highest forest score Q4 encompasses over 40% of zones.

Almost equal to share of elderly, the distribution of share of youth proceeds inversely to the park accessibility scores. While the lowest-share quartile (Q1) covers about 50% of zones at lowest forest scores, the highest-share quartile (Q4) is only represented by less than 10% of zones. Moving towards higher forest scores, Q1 almost disappears while Q4 consistently gains the share of zones, ending in about 50% of zones at highest forest score.

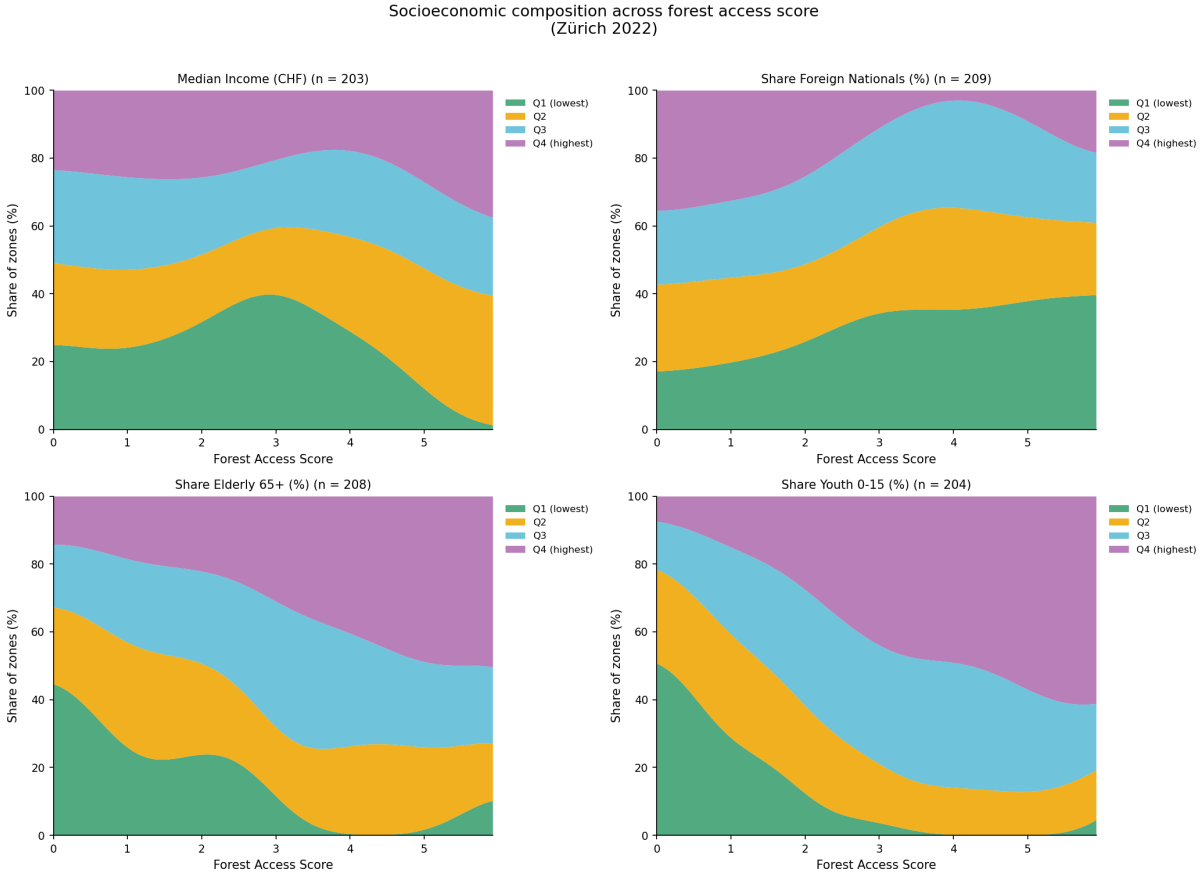


Figure 4.18: 100%-Stacked-Area-Charts for forest accessibility scores and the four variables: median income, share of foreign nationals, share of elderly (+65) and share of youth (0-15). Charts were cut off at a forest access score of 5.92 to exclude outliers (see number of zones per variable).

4.5.3 Baseline Greenness Inequality

Like for the park access score and the forest access score, 100%-Stacked-Area-Charts were generated excluding outliers above a vegetation cover share above 67.09 percent (Figure 4.19). Analogically to the park and forest scores, the figure shows the four predictors (median income, share of foreign nationals, share of elderly residents and share of youth) across the vegetation cover share of the statistical zone of Zurich. Each panel has an individual number of zones included based on the number of outliers above the set threshold.

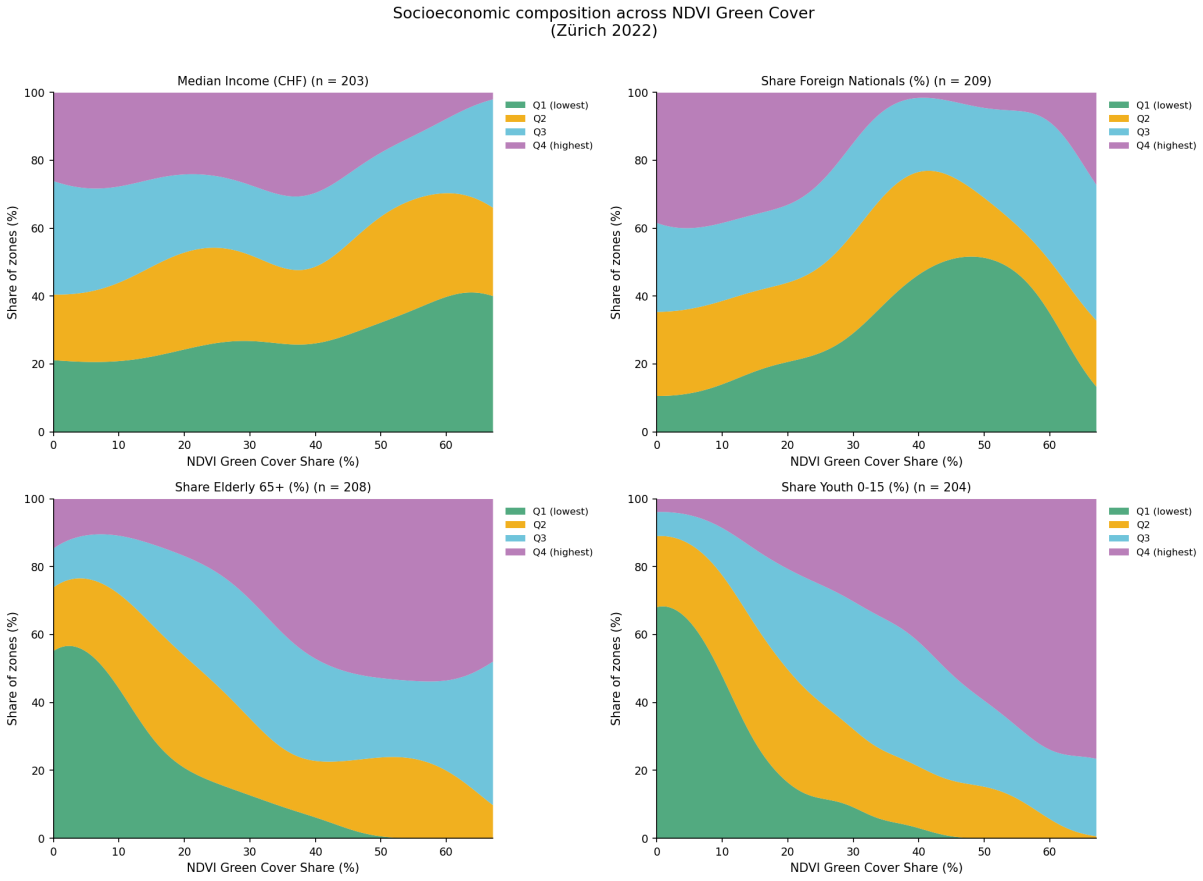


Figure 4.19: 100%-Stacked-Area-Charts for baseline greenness and the four variables: median income, share of foreign nationals, share of elderly (+65) and share of youth (0-15). Charts were cut off at a baseline greenness score of 67.09 to exclude outliers (see number of zones per variable).

The distribution of the median income is mostly evenly distributed until about 35% vegetation cover share, where the lowest-income quartile (Q1) rises from 20% of zones to about 30% of zones. Meanwhile, the Q2 and Q3 stay almost the same and the highest-income quartile (Q4) decreases to nearly zero percent of zones at highest vegetation share.

For the share of foreign nationals, the composition shifts more sharply across the vegetation gradient than for median income. At low vegetation share (0–10%), zones in

the lowest quartile (Q1) account for only around 10–20% of the distribution, while the highest quartile (Q4) makes up roughly 30–40%. As the vegetation cover increases, the share of Q1 zones rises steadily, reaching a peak of just over 50% at 40–50% vegetation share and Q4 nearly disappears in this mid-range. At the upper end of the gradient, this pattern reverses again, the Q1 share drops sharply to around 10–15% and Q4 reappears.

The share of elderly residents shows a clear monotonic shift across the vegetation gradient. At low vegetation share (0–5%), zones with lowest elderly share (Q1) dominate with 55–60% of zones, while the highest share of elderly (Q4) is entirely absent. As vegetation share increases, the Q1 share declines steadily and continuously, falling to around 10% at a vegetation share of 30% and further below 5% beyond 50% of vegetation share. Conversely, the Q4 share increases from 0% at low vegetation share to roughly 50–55% at the highest vegetation levels (above 60%). The Q2 and Q3 bands remain comparatively stable in the mid-range of the gradient, together accounting for roughly 50–60% of zones.

The share of youth residents follows a pattern similar to elderly residents but a bit steeper. At low vegetation share (0–5%), Q1 zones (lowest youth share) make up close to 70% of the distribution, while Q4 (highest youth share) is close to zero percent. The Q1 share declines sharply within the first 20% of the vegetation gradient, dropping to zero percent of zones by around 50% vegetation share. The Q4 share rises correspondingly, reaching roughly 20–25% by 20–25% vegetation share and continuing to increase to around 60–75% at the highest vegetation levels (above 50–60%). Compared to the elderly panel, the transition from Q1 dominance to Q4 dominance occurs over a narrower range of the vegetation gradient, suggesting a steeper compositional shift.

4.5.4 Comparison between Greenspace Measures

Figure 4.20 depicts the Spearman correlations of all three greenspace measures displayed by socioeconomic/demographic variable. The comparison reveals a consistent pattern of divergence between park access and the two other measures (forest access and baseline greenness) across all four predictors. For median income, none of the three measures show a statistically significant association even though the coefficients point in different directions (park access: $\rho = 0.08$, forest access: $\rho = 0.03$, baseline greenness: $\rho = -0.04$). For share of foreign nationals, park access shows a significant positive association ($\rho \approx 0.22$, $p < 0.01$), while forest access ($\rho \approx -0.19$, $p < 0.01$) and baseline greenness ($\rho \approx -0.34$, $p < 0.001$) show significant negative associations.

This divergence is more pronounced for share of elderly and share of youth. For share of elderly, park access shows significant negative associations ($\rho = -0.34$, $p < 0.001$), whereas forest access ($\rho = 0.36$, $p < 0.001$) and baseline greenness ($\rho = 0.47$, $p < 0.001$) show significant positive associations of similar or larger magnitude. The inverse pattern

is evident for share of youth where park access is significantly negatively associated ($\rho = -0.36$, $p < 0.001$), while forest access ($\rho = 0.61$, $p < 0.001$) and baseline greenness ($\rho = 0.64$, $p < 0.001$) show strong significant positive associations which are the largest coefficients observed across all comparisons in Figure 4.20.

Across all four predictors, forest access and baseline greenness track each other closely in both sign and magnitude, while park access consistently diverges from both. It even displays the opposite in three out of four predictors (share of foreign nationals, share of elderly residents and share of youth).

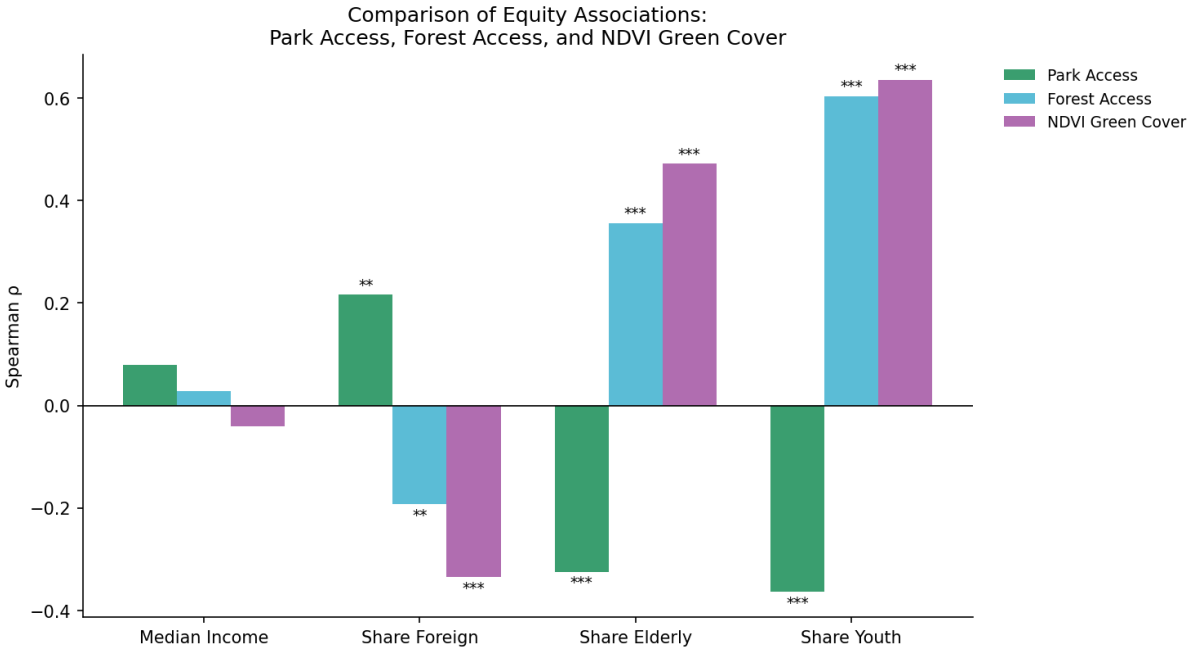


Figure 4.20: Comparison of Spearman rank correlations between park access score, forest access score and NDVI green cover and four socioeconomic & demographic variables (median income, share of foreign nationals, share of elderly and share of youth) across statistical zones of the City of Zurich (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

4.5.5 Park Characteristics Inequality

Descriptive Analysis

The full set of distributional patterns across all five park characteristic scores and four socioeconomic and demographic predictors is displayed in Figure 4.21. Several combinations show pronounced patterns: public toilet availability exhibits the clearest monotonic trend relative to median income, with the share of low-income zones declining from approximately 50% to below 15% across the score distribution. Vegetation cover depicts a strong concentration of youth-dominated zones at low scores, while path density shows the most pronounced non-monotonic/waved pattern relative to the share of elderly residents. Not all combinations display comparably distinct patterns; several (particularly those involving

bench density and the share of foreign nationals) exhibit little separation between quartile classes. These distributions are examined further through bivariate spatial cluster analysis and regression in the following sections.

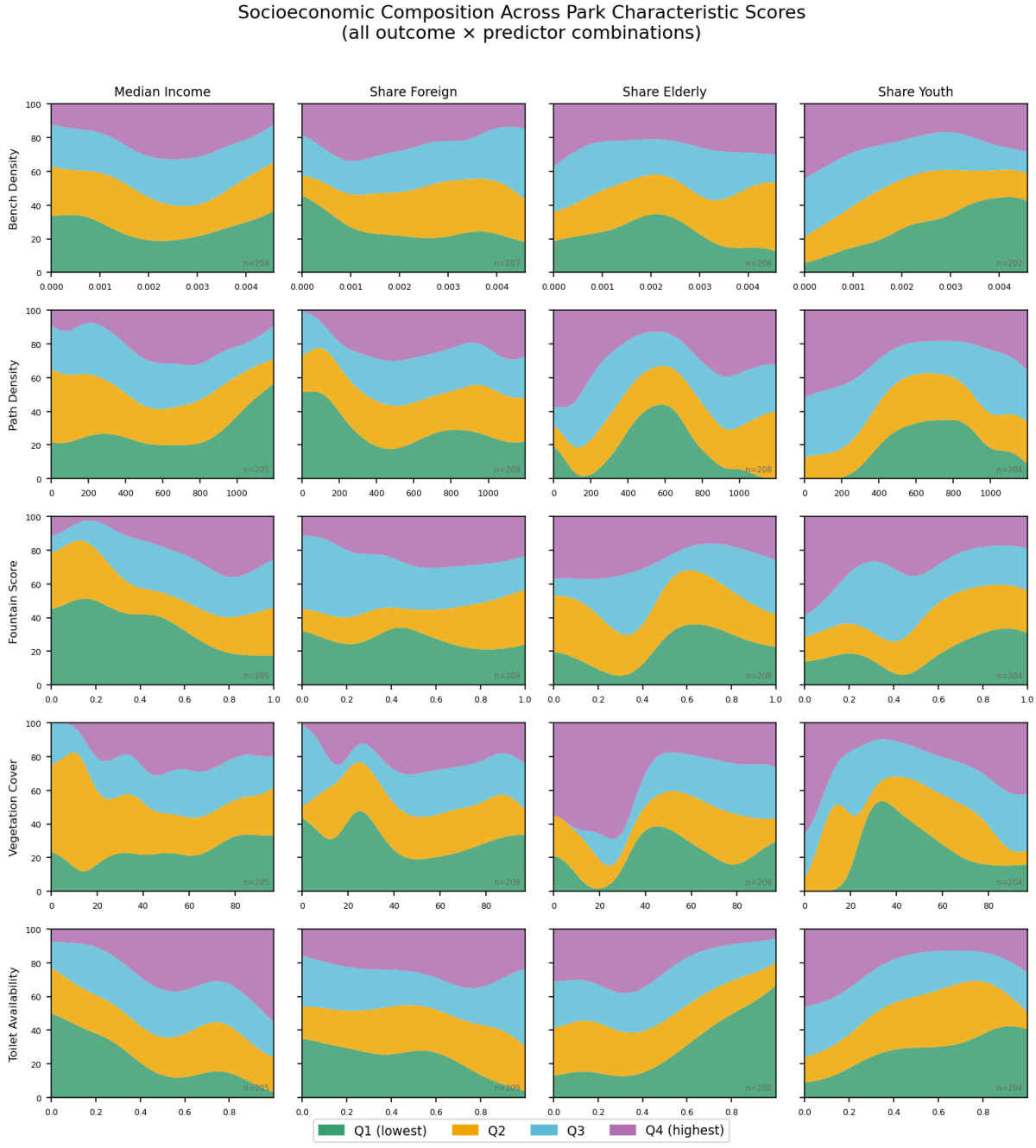


Figure 4.21: Socioeconomic composition across all five park characteristics (bench, path, fountain, vegetation, and toilet scores) and all four socioeconomic and demographic predictors (median income, share of foreign nationals, share of elderly (65+), and share of youth (0–15)).

Bivariate Spatial Cluster Analysis

Global bivariate Moran's I was statistically significant ($p < 0.05$) for 8 of the 20 outcome-predictor combinations. Toilet availability showed the most consistent spatial deprivation signal, with three of four predictors reaching significance (median income, share of elderly and share of youth), followed by fountain availability (median income and share of youth). The other three scores only show statistical significance in share of youth. Figure 4.22 summarizes the share of High-Low (HL) zones (the primary indicator of spatial deprivation) across all combinations. Cluster maps for toilet availability, the characteristic with the strongest overall pattern, are displayed in Figure 4.23. Full cluster statistics for all outcome-predictor combinations are reported in Table A.7 in Section A.9.

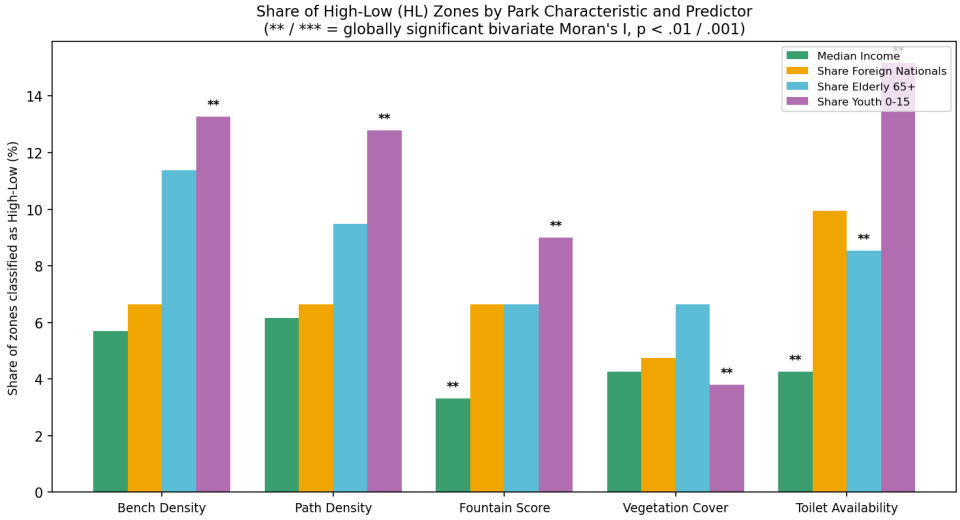


Figure 4.22: Share of statistical zones classified as High-Low (HL), the primary indicator of spatial deprivation, across all five park characteristic scores and four socioeconomic/demographic predictors. Stars indicate globally significant bivariate Moran's I (** $p < 0.01$, *** $p < 0.001$).

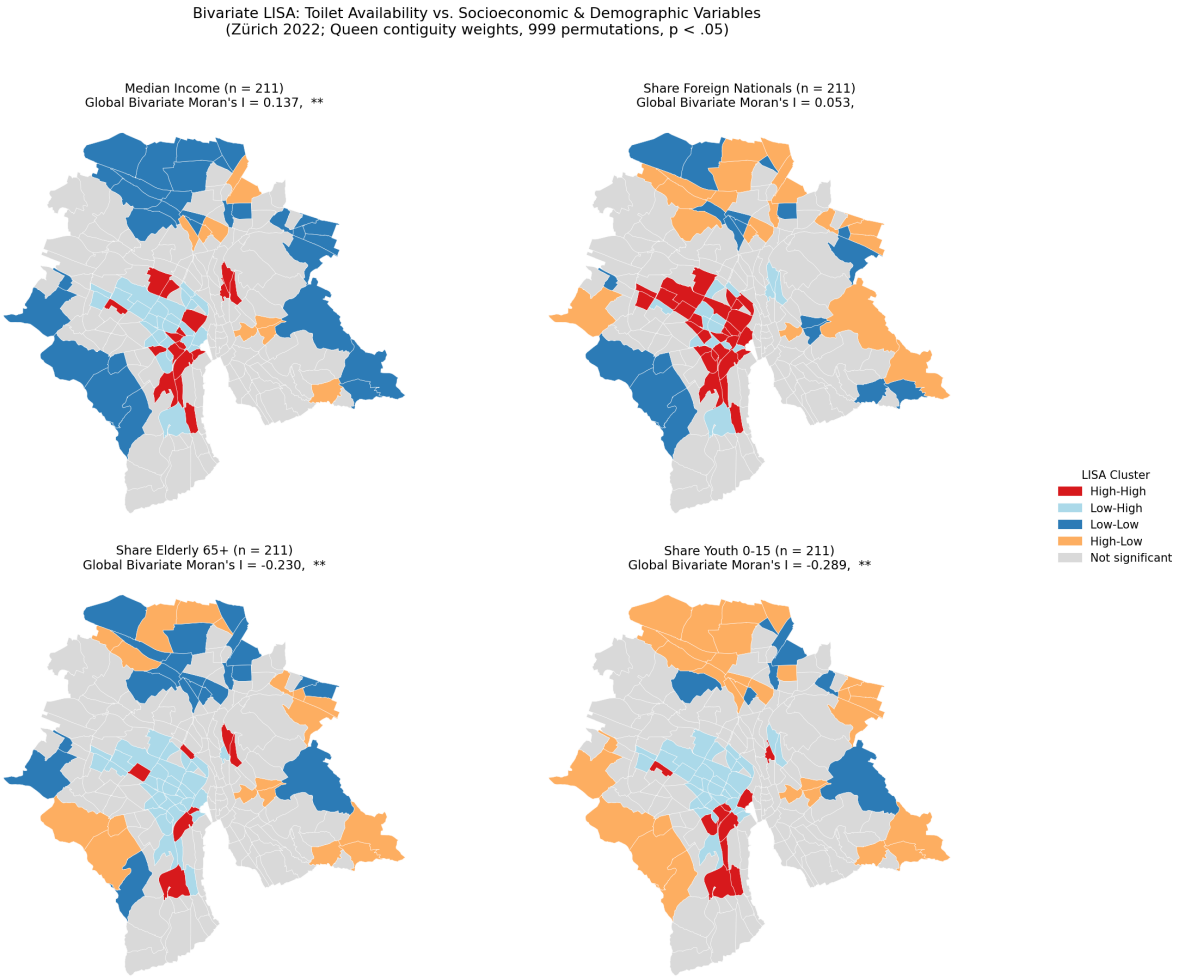


Figure 4.23: Bivariate LISA cluster maps for toilet availability, the park characteristic with the most consistent spatial deprivation signal (three of four predictors globally significant; see Figure 4.22).

Regression Analysis

While the bivariate LISA results in Section 4.5.5 identify localized clusters of spatial deprivation, they do not account for the joint influence of multiple socioeconomic and demographic predictors, nor for the global spatial dependence structure of the outcome variables themselves. Standardized OLS coefficients and model fit statistics reported in Table 4.10 and Table 4.11, address this limitation.

Explained variance ranges from $R^2 = 0.018$ (path density) to $R^2 = 0.282$ (public toilet availability). Moran's I of the OLS residuals was positive and highly significant for all five outcomes (range: 0.383–0.719, $p < 0.001$), which confirmed the presence of substantial global spatial autocorrelation already suggested by the clustering patterns observed in Section 4.5.5. They furthermore indicate that a non-spatial specification is insufficient.

Spatial Error Models were therefore estimated for all five outcomes. Estimated λ coefficients range from 0.771 (vegetation cover) to 0.944 (bench density), confirming strong

residual spatial dependence across all park characteristics. Under the SEM specification, the majority of socioeconomic and demographic effects that were significant under OLS ended up non-significant. Notably, several predictors identified as locally significant in the bivariate LISA analysis (including share of youth for bench and path density) did not retain significance once the joint, spatially corrected model was applied. This finding suggests that their bivariate spatial clustering reflects broader spatial structure rather than a robust independent association.

Table 4.10: Standardised OLS and Spatial Error Model (SEM) coefficients for park characteristic scores

Outcome	Predictor	OLS β	SEM β
Bench density	Median income	0.111	0.095**
	Foreign nationals	−0.164	−0.090
	Elderly (65+)	−0.030	0.014
	Youth (0–15)	−0.314***	0.041
Path density	Median income	−0.012	0.102**
	Foreign nationals	−0.056	−0.076
	Elderly (65+)	0.050	0.006
	Youth (0–15)	−0.133	0.049
Fountain availability	Median income	0.204**	0.100*
	Foreign nationals	−0.308***	−0.126*
	Elderly (65+)	−0.027	0.021
	Youth (0–15)	−0.256***	0.035
Vegetation cover	Median income	0.072	0.136*
	Foreign nationals	0.055	0.016
	Elderly (65+)	−0.056	−0.012
	Youth (0–15)	0.323***	0.197*
Toilet availability	Median income	0.287***	0.028
	Foreign nationals	−0.318***	−0.050
	Elderly (65+)	−0.360***	−0.096*
	Youth (0–15)	−0.332***	0.019

Note. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4.11: Model fit statistics and spatial autocorrelation of OLS residuals for park characteristic scores

Outcome	OLS R^2	Moran's I (residuals)	SEM λ	SEM pseudo-R^2
Bench density	0.096	0.662***	0.944	0.000
Path density	0.018	0.719***	0.927	0.001
Fountain availability	0.120	0.522***	0.892	0.037
Vegetation cover	0.094	0.383***	0.771	0.078
Toilet availability	0.282	0.489***	0.928	0.104

Note. Moran's I computed on OLS residuals using Queen contiguity weights (999 permutations); *** $p < 0.001$ for all. λ = spatial error coefficient (Maximum Likelihood).

Median income remained a significant positive predictor in four of the five models (bench density, path density, fountain availability, vegetation cover) and was the only predictor to remain significant for bench and path density after spatial correction. Vegetation cover retained a significant positive association with the share of youth ($\beta = 0.197$, $p < 0.05$), consistent with its bivariate LISA pattern. Public toilet availability, the characteristic with the most consistent bivariate deprivation signal in Section 4.5.5, showed a more selective pattern under SEM. Median income lost significance, while the share of elderly remained a significant negative predictor ($\beta = -0.096$, $p < 0.05$).

Chapter 5

Discussion

This chapter interprets the results presented in Chapter 4 in consideration of the three research questions and their hypotheses. Section 5.1 briefly goes over the extent to which each hypothesis was confirmed. Section 5.2 and Section 5.3 then reflect on RQ1 and RQ2, establishing the methodological and geographic context against which the findings for RQ3 are discussed (Section 5.4). Furthermore, Section 5.5 discusses park characteristics in association with the four predictors. Section 5.6 captures the difference between greenspace measures. The chapter closes by drawing implications for urban planning (Section 5.7) and reflecting on the limitations of the study (Section 5.8).

5.1 Summary of Key Findings

This section summarizes the extent to which Hypothesis 1 to 3 were supported. Research Question 1 and 2 addressed the definition of urban parks and the socioeconomic/demographic geography of Zurich's statistical zones. As descriptive and methodological questions, they are not associated with testable hypotheses and are discussed on their own terms in Section 5.2 and Section 5.3.

Research Question 3, however, was operationalized through Hypothesis 1 to 3, which this section now summarizes. Hypothesis 1 proposed that correlations between socioeconomic/demographic characteristics and park access/characteristics are statistically significant but modest in magnitude. This received only mixed support. OLS models showed effects consistent with the expectation, but they disappeared once the Spatial Error Model accounted for spatial autocorrelation. This indicates that the effect stemmed from the shared spatial clustering rather than from a direct relationship between inequality and park access.

Hypothesis 2 proposed that zones with lower median income and higher shares of foreign nationals have lower park accessibility scores. This was not supported for share of foreign nationals. Its association even ran counter to the hypothesized direction. Furthermore, the hypothesis was only weakly supported for median income once spatial structure was

accounted for.

Hypothesis 3 expects that amenity availability is lower in zones with lower median income, higher shares of foreign nationals and higher shares of elderly or youth residents. This received partial support, depending on park characteristic. Median income remained a significant predictor of many park characteristics even after spatial correction. Share of foreign nationals showed no association with either park accessibility or characteristics. The shares of youth or elderly residents were each linked to only one specific characteristic. Across all three hypotheses, the strength and sometimes the direction of these associations depended on greenspace measure. A divergence that is discussed in Section 5.6.

5.2 Park Dataset Construction

A consistent definition of urban parks has remained elusive in the greenspace literature (Section 2.5.1). Research Question 1 was therefore posed to address this gap directly. The following reflects on how the definition and dataset construction described in Section 2.2.1 and Section 3.2 answered it. Furthermore, the limitations of this process were revealed.

As identified in Section 2.5.1, the absence of a consistent and operationalizable park definition demonstrates a gap in greenspace literature. It has to some extent undermined the comparability of studies. By adapting the criteria proposed by Kraemer and Kabisch (2021)[1] this thesis operationalized a park definition that is both conceptually grounded and directly translatable into GIS-based spatial analysis. This transparency represents a methodological contribution in itself. Rather than treating park identification as an unproblematic pre-processing step, the multi-stage filtering and manual inspection (Section 3.2.2) make explicit which spatial features were included or excluded.

The manual inspection turned out to be essential for the dataset construction. Of the 173 candidate polygons that passed automated filtering, 69 were subsequently excluded. Road strips, private courtyards and functional green belts that met the size and land-use criteria on paper but did not fulfill a genuine park function. The retained 104 parks contained, on average, more than seven times as many benches as the excluded features (23.6 vs. 3.3). This suggests, that the automated filtering based on land-use attributes systematically retains greenspace that lacks recreational infrastructure. It points to a broader methodological insight for future greenspace disparity research. Purely attribute-based or size-based park delineation, without a manual or amenity-informed verification step may overstate park provision in ways that are not random. Rather, it might be systematically tied to the presence or absence of usable infrastructure.

At the same time, several limitations of the definition and dataset construction need reflecting. First, the 0.5 ha minimum size threshold, while grounded in established planning

[1] public accessibility, absence of a distinct competing function, substantial vegetated surface and distinction from forest areas

and public health guidance, excludes small pocket parks and neighborhood squares. Given that such small-scale greenspace is disproportionately common in dense inner-city zones, this threshold may systematically under-represent greenspace provision. Especially in the areas where residents rely most on small, walkable open spaces. This limitation has direct relevance to the inequality interpretation in Section 5.4.

Second, reliance on OSM data introduces a degree of data quality that is inherently uneven. OSM tagging completeness and consistency depend on volunteer contribution activity, which is not guaranteed to be spatially uniform across the city. This effect was limited by using primarily geometries from the city's department of greening, making the share of OSM geometries smaller.

Third, the manual verification step, while methodologically necessary, relied on the researcher's visual interpretation of satellite and StreetView imagery. This introduced an element of subjective judgment that could not be fully standardized and images could not be guaranteed to reflect present-day conditions in all cases.

Finally, the municipal greenspace dataset (Grün Stadt Zürich, 2026b) by construction excludes parks under cantonal or federal jurisdiction, while swissTLM3D (swisstopo, 2025b) partially addressed this gap. Some inconsistency between data sources in how park boundaries are delineated cannot be fully ruled out.

To sum up, these reflections suggest that while the adopted park definition provides a transparent and reproducible answer to RQ1, the choice of size threshold and data sources are not neutral methodological decisions. They carry inequality implications of their own that should be kept in mind when interpreting the accessibility and characteristics analyzed in Section 5.4 and Section 5.5.

5.3 Socioeconomic & Demographic Indicators

This section addresses Research Question 2 by interpreting the spatial patterns of the four socioeconomic and demographic predictors identified in Section 4.4.1. The spatial patterns confirm that Zurich's socioeconomic and demographic composition is not randomly distributed. Rather, it follows structured, historically grounded geographic gradients. This has direct implications for how the disparity findings in Section 5.4 can be interpreted.

High income clusters in the lakeside and elevated eastern districts, while low-income clusters concentrate in western and south-western former industrial areas. This reflects Zurich's long established residential geography rather than a recent or incidental pattern. The near-inverse spatial relationship between income and foreign national share (high concentration clusters of foreign nationals in the north and north-east and lower-income periphery) points to a settlement geography shaped by housing affordability. And not income alone since the two variables show no significant correlation at the zone level (Table 4.6). This absence of a direct income-nationality relationship suggests that residential

sorting in Zurich operates along dimensions not captured by income. Even though income and nationality spatially cluster inversely. Possible dimensions that influence this residential sorting could be housing type, tenure or neighborhood networks. The pattern aligns closely with Plüss (2024), who documents that Zurich's northern and western districts combine lower income, higher shares of foreign nationals and the city's oldest building stock. This places the areas with lower socioeconomic status simultaneously under the highest redevelopment pressure.

Age structure follows a distinct logic. The pronounced clustering of youth share in the southern periphery is paired with a Low-Low cluster in the inner city (Figure 4.13). This may reflect life-stage-driven residential sorting, whereby household composition shapes location preferences across a city (Section 2.4.2; Pagani et al. (2021)). Young families may prioritize housing functions more readily available in peripheral zones, such as space or affordability. Inner-city zones, by contrast, remain disproportionately populated by working-age adults and, to a lesser extent, elderly residents. The pattern of elderly share is more dispersed, with only moderate clustering in southern lakeside zones. This suggests that older residents are less spatially concentrated than the other three predictors. This is also reflected in its comparatively lower global Moran's I ($I = 0.304$) relative to youth share ($I = 0.510$).

Overall, these patterns establish that Zurich's socioeconomic and demographic geography is itself spatially structured before any greenspace measure enters the analysis. This descriptive geography forms the empirical basis against which Hypothesis 1 (H1)–Hypothesis 3 (H3) are tested in Section 5.4 and Section 5.5. This pre-existing residential sorting means that groups from lower and higher socioeconomic status were already unevenly distributed across the city. Any observed association between lower socioeconomic status and lower park access must therefore be interpreted against this context. It cannot be assumed that the origin is planning-driven.

5.4 Park Accessibility

In this section the first part of Research Question 3 will be addressed by evaluating Hypothesis 1 and Hypothesis 2 against descriptive, bivariate and regression evidence presented previously in Section 4.5.

The descriptive and bivariate spatial evidence only partially support Hypothesis 2. For median income, the descriptive pattern is broadly consistent with the hypothesized direction. Higher-income zones are increasingly overrepresented among zones with higher park access scores. Furthermore, the LISA analysis identifies a low income co-occurring with low park access as the dominant deprivation relevant cluster type. This finding matches the broader international pattern of income-based disparities in park access as reported by Boone et al. (2009), Byrne and Wolch (2009), and Rigolon et al. (2018).

For share of foreign nationals, however, the pattern runs counter to Hypothesis 2. It also does not completely agree with inequality literature which generally associates higher shares of ethnic minorities with poorer park access (Rigolon, 2016; Talen, 1997). This divergence is notable given that foreign nationals in Switzerland face documented structural inequality in housing and labor market access (Ebner & Helbling, 2016; Zschirnt et al., 2025). Also that non-Swiss residents in Zurich specifically concentrate in the city's northern and western districts with lower socioeconomic status (**pluss_stadt_2024**). One possible explanation is that these northern districts, despite their broader lower socioeconomic status, happen to be comparatively well-served by parks. This means that the counterintuitive result may reflect Zurich's specific spatial coincidence of park provision and immigrant settlement geography. This rather than contradicting the structural disparity documented elsewhere in the literature. Both the descriptive distribution and the significant positive global bivariate association point in the same direction. Zones with higher shares of foreign nationals tend to have, if anything, better rather than worse park access. This does not rule out localized deprivation. A high foreign national share/low park access cluster is still identifiable in a subset of zones. Yet it is not the dominant pattern across the city. Elderly and youth shares, which were covered by Hypothesis 3 more broadly, show clear high elderly/youth share and low park access clustering. This would indicate that these two demographic groups are the ones most consistently co-located with poor park access.

The regression results add an important qualification to the picture. The OLS model partially supports Hypothesis 1. Income, elderly share and youth share are statistically significant predictors of the park access score. Meanwhile, the coefficient for foreign nationals share remains non-significant like in the descriptive pattern mentioned above. However, once spatial autocorrelation is accounted for in the Spatial Error Model (Section 4.5.1), none of the four predictors remain statistically significant. This suggests that the associations identified at the OLS stage are largely attributable to the shared spatial structure of the predictors and the outcome (Section 5.3). And not to a direct relationship between low status and park accessibility. In this sense, Hypothesis 1 receives mixed support depending on model specification. The OLS results are consistent with H1's expectation of significant but modest associations. Further, in the primary Spatial Error Model none of the four predictors remain statistically significant. The SEM specification is preferred on methodological grounds (Section 4.5.1). The more defensible conclusion is therefore that H1 is not supported. The relationship between low status and low park accessibility appears statistically identical to zero once spatial autocorrelation is properly accounted for. This is a stronger conclusion than merely hypothesized modest support.

Overall, the evidence does not support H2 for share of foreign nationals and only weakly supports it for median income once spatial structure is properly accounted for.

These results warrant closer inspection of the spatial error term itself. The SEM's

spatial autoregressive parameter is not only high ($\lambda = 0.939$, $p < 0.001$) but the model also outperforms the non-spatial specification in overall fit ($AIC = 344.7$ compared to 580.6 for OLS). A λ of this magnitude indicates that the omitted spatial process is strong. Park access scores in neighboring zones remain highly correlated even after the four predictors are accounted for. And this well beyond what income, nationality and age structure alone can explain. It is precisely why the SEM removes the significance of the individual predictors that were significant under OLS. Much of the variance that appeared to be explained by median income, elderly share and youth share is, in fact, explained by shared, unmodeled spatial structure.

Therefore, the question emerges what this omitted spatial process might represent. Section 5.3 established that Zurich's socioeconomic and demographic geography is itself spatially structured along a historically grounded, partly center-periphery logic. Foreign nationals concentrate in the northern and north-eastern periphery, youth share clusters in the southern periphery. High income clusters in the lakeside and elevated eastern zones. Park accessibility follows a distinct but overlapping spatial logic. As Section 5.6 will discuss, parks concentrate in centrally located, older and more built-up zones. Meanwhile, forest and baseline greenness, as well as youth- and elderly-dominated peripheral zones are concentrated toward the urban edge. The strong λ therefore plausibly captures this underlying center-periphery structure of park provision. It is historically shaped by the location of Zurich's oldest and densest neighborhoods and their parks. This is not a process causally tied to any single predictor.

It is important to be precise about what this does (and does not) change relative to the descriptive finding in Section 4.5. These regression models are aimed at prediction rather than at establishing the causal mechanism behind an individual relationship. The SEM result does not overturn the finding that particular demographic groups (notably zones with high shares of elderly and youth residents) experience lower park accessibility (Section 4.5.1, Figure 4.17). This descriptive and bivariate pattern still holds. What changes is the explanation. The apparent relationship is not driven by the demographic composition of a zone directly, but by a shared, omitted spatial process. This process happens to spatially coincide with where these demographic groups live.

5.5 Park Characteristics

This section discusses the second part of Research Question 3 by evaluating Hypothesis 2 and Hypothesis 3 against the descriptive, bivariate and regression evidence for the five park characteristic scores presented in Section 4.5.5.

Median income emerges as the most consistent predictor of park characteristics once spatial autocorrelation is accounted for. It remains significant in four of the five Spatial Error Models (vegetation cover, path density, bench density, and fountain availability).

Furthermore, it appears to remain the only robust predictor for bench and path density. This pattern backs up H2 with respect to income. It also echoes the finding of Crawford et al. (2008) that public open spaces in higher-status neighborhoods contain a greater number of amenities. This contrasts with the accessibility results in Section 5.4. There, income's association with park access disappeared once spatial autocorrelation was accounted for. Income's effect on park characteristics persists the same correction. This suggests that once spatial structure is controlled for, income no longer explains whether a zone has a park nearby, but continues to explain what that park offers.

Share of foreign nationals, in contrast, shows no significant SEM association with any of the five characteristics. Further, only two OLS coefficients (fountain and public toilet availability, both negative) are significant. This mirrors the accessibility findings in Section 5.4. Furthermore, it reinforces the conclusion that the settlement geography of foreign nationals across Zurich's statistical zones does not translate into a systematic disparity in either park reach or park equipment. Or at least not once income and the other predictors are held constant.

The two demographic predictors reveal a more differentiated picture. Share of youth is the predictor most frequently significant under OLS (negative: bench, fountain, public toilet; positive: vegetation). Yet three of these four associations lose significance under SEM. This is consistent with the localized bivariate LISA clusters reported in Section 4.5.5. It confirms that youth's apparent influence on bench, fountain and public toilet provision is largely attributable to the shared spatial structure. Youth-dominated peripheral zones (Section 5.3) and the outcomes themselves overlap spatially, rather than being independently connected. This spatial inflation is a substantive finding in its own right. It indicates that the observed pattern is a property of Zurich's residential geography rather than of amenity planning specifically targeting or neglecting young families. Vegetation cover is the exception. Its positive association with youth share persists after spatial correction. This suggests that vegetated area in parks is not merely co-located with youth-dominated periphery but a more spatially fundamental feature of it. Plausibly reflecting the lower building density and larger plot sizes characteristic of the peripheral, family-oriented zones identified in Section 5.3.

Share of elderly residents, in comparison, shows almost no association with park characteristics once spatial structure is accounted for. There is only one exception: public toilet availability. Its negative SEM coefficient is the only demographic effect to remain significant across all five outcomes. Toilet availability was also the characteristic with the most consistent bivariate and regression evidence. This strengthens the interpretation that needs of elderly residents can often be neglected by park designs. Exactly how S. Chen et al. (2020) have observed. Existing park quality frameworks are rarely designed with elderly populations in mind. Yet these populations rely comparatively more on toilet facilities for park visitation (Section 2.2.3). The result suggests that Zurich's park provision broadly

serves elderly residents in most aspects. But systematically, it underserves this specific and mobility-relevant need.

To sum up, the evidence lends only partial and characteristic-specific support to Hypothesis 3. Rather than a uniform pattern of lower amenity availability in lower status zones, the results point towards a more selective image. Income is consistently related to amenity provision across most characteristics, while foreign national share is not associated with any. The demographic predictors each show one specific, targeted association instead (youth with vegetation, elderly with public toilets). A pattern of broad inequality for groups with lower socioeconomic status does not emerge in terms of park characteristics. This selectivity reflects the divergence already observed for park accessibility in Section 5.4. It confirms that the strength and direction of inequality associations in Zurich depend on several factors. These include which characteristic, which predictor and which model specification are considered.

5.6 Greenspace Measures

The inequality findings presented in Section 5.4 and Section 5.5 regard specifically the park accessibility and park characteristics. This section aims to investigate whether the same conclusions would hold for other measures of greenspace in the city. In the framework of this thesis, park accessibility, forest accessibility and baseline greenness (Section 4.2.4) are compared. This comparison seeks to find advantages and limitations of the different types of greenspace measures for the greenspace inequality discussion.

The strong positive correlation between forest accessibility and baseline greenness ($\rho = 0.768$) reflects their share vegetative basis. Forests represent densely vegetated, contiguous landscape units that dominate a zone's overall vegetation cover. The negative correlation between park accessibility and both forest accessibility ($\rho = -0.456$) and baseline greenness ($\rho = -0.563$) is notable. Parks concentrate in centrally located, built-up zones, whereas forests and baseline greenness cluster at the urban periphery. Baseline greenness, as an aggregate vegetation measure, is therefore structurally closer to forest distribution than to park distribution. It does not adequately substitute for park-specific accessibility measures. That's a distinction that proves decisive in the interpretation of the inequality results.

The consequence of this divergence becomes apparent once the three measures are related to the socioeconomic and demographic predictors (Section 4.5.4). For median income, none of the measures is significantly associated with the predictor which makes the choice of greenspace measure largely inconsequential in this case. For the remaining three predictors, however, the choice of measure changes not only the strength but the direction of the observed relationship. Share of foreign nationals is positively associated with park access but negatively associated with both forest access and baseline greenness.

The reversal is the strongest for the two age-structured predictors. Share of elderly and share of youth are both negatively associated with park access, yet positively associated with the two other greenspace measures. Furthermore, the youth coefficients ($\rho = -0.36$ for park access versus $\rho = 0.61$ for forest access and $\rho = 0.64$ for baseline greenness) stand out. They represent the largest effect sizes observed anywhere in the inequality analysis. The share of elderly shows similar values, yet they are not as extreme as the youth findings.

This reversal bears directly on Hypothesis 2 and Hypothesis 3. Had this thesis relied on forest accessibility or baseline greenness rather than the park measure, the conclusion would have shifted substantially. Youth- and elderly-dominated zones would have appeared as the most greenspace-advantaged rather than the part of the city with the lowest socioeconomic status. This would have reversed rather than merely soften the conclusions on age-based disparity. This is not evidence of inconsistent measurement but a major finding about Zurich's urban form. The peripheral, lower-density zones that house a disproportionate share of families and elderly residents (Section 5.3) border the city's forested edges. Meanwhile, the centrally located, amenity-equipped parks these groups depend on remain comparatively scarce. Aggregate greenness indicators risk masking the specific disparity in reachable park space that this thesis aimed to capture.

To sum up, these results show that disparity conclusions drawn from greenspace data depend strongly on which spatial extent and greenspace type is measured. This further underscores the need for measure-specific rather than aggregate assessments in future greenspace inequality research.

5.7 Implications for Urban Planning

The results from the inequality analysis are more complex than just to label the park provision as equitable or inequitable. Hypothesis 1 is not supported once spatial autocorrelation is accounted for (Section 5.4). The data therefore do not support a general claim that income, nationality composition or age structure directly predicts park access. Planning interventions aimed purely at closing spatial access gaps by income would therefore misdiagnose where the actual disparity lies. If anything, specific zones should be investigated to improve park accessibility.

The more actionable finding concerns park characteristics rather than park presence. Median income remains a robust predictor of bench, path, fountain and vegetation provision even after spatial autocorrelation (Section 5.5). This means that among zones with comparable access, lower-income neighborhoods tend to be served by less equipped parks. It points toward amenity-level reviewing and targeted upgrading (benches, paths and fountains in particular) as a more precise lever than adding new park area in already accessible zones. Public toilet availability offers the clearest single target. Its association with the share of elderly residents remains significant across all specifications (Section 5.5).

This identifies a concrete, mobility-relevant infrastructure gap that current park provision does not adequately address for an aging population.

The divergence across greenspace measures (Section 5.6) carries a further implication for how park inequality should be monitored going forward. Forest accessibility and baseline greenness both diverge from park accessibility. Using generic vegetation indicators such as NDVI-derived green cover as a proxy for park provision therefore risks misrepresentation. Specifically, it may systematically misrepresent which zones are underserved. The risk is especially pronounced for youth- and elderly-dominated zones at the urban periphery. Municipal greenspace monitoring should therefore track park-specific accessibility and amenity indicators separately from general urban greening targets. An increase in aggregate vegetation cover should not be treated as evidence of improved inequality.

Finally, the manual verification step in the park dataset construction (Section 5.2) has a direct planning consequences. Automated, attribute-based identification of park space substantially overstated recreational infrastructure relative to amenity-verified parks. Municipal greenspace inventories used for planning or reporting purposes should therefore incorporate a comparable verification step, rather than relying on land-use classification alone.

5.8 Limitations

5.8.1 Data and Methodological Constraints

There are a few data and methodological constraints that qualify the findings presented above. First, the analysis is cross-sectional, combining socioeconomic and demographic data from the year 2022 with NDVI data from 2025. Greenspace data is drawn from the same year as the NDVI data. Any change in population composition or vegetation cover between these reference points could not be captured. In addition, the acknowledged seasonal bias in the NDVI imagery (Section 3.6) adds further uncertainty to the baseline greenness measure specifically. A similar issue is with the greenspace dataset of the city. Many park geometries are retrieved from it, as it depicts recent greenspaces. It is therefore a few years more recent than the socioeconomic and demographic data from 2022.

Second, all analyses operate at the statistical zone level. This entails that relationships observed between zone-level scores and zone-level socioeconomic composition do not necessarily hold for individual residents. Furthermore, the boundaries of the 211 statistical zones themselves are an administrative rather than behaviorally grounded delineation of neighborhoods. This raises the concern of the modifiable areal unit problem. Assuming residents within a zone are homogeneous in socioeconomic, demographic as well as behavioral standards, does not completely depict reality. The statistical zone level was the highest resolution for the extent of this thesis. The results come as close to reality as

possible.

Third, the network-based accessibility measure (Section 3.3) captures the presence and distance of reachable parks. However, it does not consider the nature of the walking environment itself. Sidewalk quality, traffic exposure, perceived safety and topography are not represented. Yet they plausibly shape whether a park is realistically accessible and therefore used.

Fourth, the socioeconomic and demographic predictors are grounded in the inequality literature and data availability at the city level (Section 3.7). However, they do not exhaust the dimensions along which socioeconomic position could be operationalized. Housing tenure, education and household composition are not available at the statistical zone level. They could therefore not be tested as alternative or complementary predictors. The median income variable itself is further restricted to the basic tax rate (*Grundtarif*) for methodological reasons (Section 3.7.1). This means the measure reflects unmarried taxpayers specifically rather than the zone's full income distribution. A median income covering both married and unmarried residents is not available. Such measure would already be more representative of real income dynamics.

Finally, the regression models operate on a comparatively small effective sample size, given 211 zones and four correlated predictors. This limits statistical power to detect modest associations. The limitation is particularly relevant once the spatial error term absorbs a substantial share of the variance (Section 4.5.1).

5.8.2 Generalisability

The findings are also bound the specific urban and institutional context of Zurich. The city's park inequality outcomes emerge against a specific backdrop (Section 1.5). This includes of comparatively high overall income, extensive public greenspace investment and a compact city model with strong municipal land-use control. These conditions differ substantially from the North American urban contexts that dominate the greenspace inequality literature (Section 2.4). There, more pronounced income and racial segregation coincide with more market-driven park provision. The absence of a robust income-accessibility relationship under the Spatial Error Model may therefore partly reflect Zurich's specific planning history. It should not be read as a universal absence of park disparity concerns. Furthermore, it cannot be seen as evidence that income-based disparities in park access are negligible. This applies particularly to cities with different governance and settlement patterns.

The single-city design further limits external validity. With 104 parks and 211 zones drawn from one municipality, the results describe one particular configuration of urban form. The specific divergence between park and forest accessibility is itself partly a function of Zurich's topography and settlement history. Forested slopes yield a densely built urban core. Cities with a different spatial arrangement of green infrastructure or topography

may not exhibit the same divergence between greenspace measures.

The methodology is more transferable than the specific findings. The park definition and multi-stage verification procedure and the network-based accessibility scoring can, in principle, be applied to other cities. However, it would require comparably fine-grained municipal greenspace and building-level population data, which are not universally available. Also, the manual verification step in particular scales poorly to larger or data-sparse cities without dedicated resources.

Chapter 6

Conclusion

6.1 Contributions

This thesis makes three contributions to the study of urban greenspace inequality. Methodologically, it operationalizes a transparent and reproducible park definition, combining automated attribute-based filtering with manual verification (Section 3.2). A substantial share of candidate polygons excluded at the manual stage, despite meeting size and land-use criteria on paper. This demonstrates that attribute-based delineation alone systematically overstates recreational infrastructure. The verification protocol developed here offers a transferable safeguard against this bias for future greenspace evaluations. Empirically, the thesis moves beyond composite greenspace indices by analyzing five park characteristics separately under a Spatial Error Model specification. This specification reveals associations with socioeconomic and demographic status that a single aggregate score would have masked. Most notable were the selective, characteristic-specific patterns for median income, youth and elderly residents (Section 5.5). Conceptually, park accessibility is compared against forest accessibility and NDVI-derived baseline greenness (Section 5.6). These measures diverge not only in magnitude but in the direction of their association with socioeconomic and demographic predictors. This finding calls for caution against treating aggregate vegetation indicators as proxies for park-specific provision. It constitutes a methodological contribution in its own right for greenspace disparity research more broadly.

6.2 Key Findings

The central finding of this thesis is that socioeconomic disparities in Zurich's greenspace manifest through amenity provision not spatial access. Across the three research questions, the findings converge on this one picture. Greenspace inequality in the city is differentiated rather than uniform. Park accessibility itself shows no independent, predictive association

with socioeconomic or demographic predictors once spatial autocorrelation is accounted for. This means Hypothesis 1 (correlation is present but moderate) is not supported under the primary specification. This does not mean the underlying disparity disappears. The descriptive and bivariate evidence (Section 4.5.1) still shows a clear pattern. Zones with high shares of elderly and youth residents are disproportionately associated with lower park accessibility. Rather, the Spatial Error Model's high and significant spatial parameter ($\lambda = 0.939$, Section 5.4) points elsewhere. It indicates that this apparent relationship is explained by a strong, shared spatial process (plausibly Zurich's center-periphery pattern of park provision). This process, not a direct effect of demographic composition, is the more likely explanation.Associations that are visible under OLS or bivariate LISA analysis therefore reflect this shared spatial structure of Zurich's residential geography. An independent, predictive relationship is rather unlikely.

Park characteristics tell a different story. It is where the disparity actually surfaces. Median income remains the most consistent predictor of amenity provision. The share of foreign nationals, by contrast, shows no significant association with either park accessibility or characteristics. The two demographic predictors, share of youth and share of elderly residents, each surface one specific, targeted association. Youth is linked to vegetation cover, elderly to public toilet availability. The comparison across greenspace measures adds a further qualification. Had this thesis relied on forest accessibility or baseline greenness instead of park accessibility, the conclusions on age-based inequality would have shifted substantially. They would have been reversed rather than merely softened. In conclusion, these results suggest that greenspace disparity in Zurich is not a question of whether parks are reachable. It is a question of what they offer once one gets there. And this conclusion depends markedly on which combination of measure, predictor and model specification is examined.

6.3 Policy Implications

The inequality analysis does not support a general claim that park accessibility is directly driven by median income, nationality composition or age structure. This holds once spatial autocorrelation is accounted for. This does not mean these groups do not experience lower park access in practice. Rather, the underlying cause appears to be a shared spatial process. This situation could be a historical, center-periphery structure of park provision rather than the demographic composition of a zone itself. Planning interventions aimed narrowly at closing access gaps through socioeconomic or demographic targeting would therefore misdiagnose the disparity's location. Interventions should instead target the specific, historically underserved zones themselves, regardless of who currently lives there. Zone-specific investigation, rather than a citywide accessibility target, is found to be the more appropriate starting point for policy implications.

These policy conclusions are, however, bound to Zurich's specific planning context. This includes comparatively high overall income, extensive public greenspace investment and strong municipal land-use control. It differs from the North American contexts that dominate the greenspace inequality literature. The absence of a robust income-accessibility relationship under the Spatial Error Model should therefore not be generalized. This applied particularly to cities with different governance and settlement patterns.

The more actionable finding concerns park characteristics rather than park provision. Median income remains a robust predictor of bench, path, fountain and vegetation provision even after accounting for spatial autocorrelation (Section 5.5). This indicates that among zones with comparable park access, lower-income neighborhoods tend to be served by less equipped parks. Amenity-level upgrading, particularly of benches, paths and fountains, would therefore constitute a more precise policy lever. This is more precise than adding new parks in already accessible zones. Public toilet availability offers the clearest single target, given its consistent association with the share of elderly residents. It points to a concrete, mobility-relevant infrastructure gap in an aging population.

The divergence between park accessibility, forest accessibility and baseline greenness (Section 5.6) has a further implication. Municipal greenspace monitoring should track park-specific accessibility and amenity indicators separately from generic vegetation targets. An increase in aggregate NDVI-derived green cover (baseline greenness) should not be treated as evidence of improved park disparity. Doing so risks misrepresenting which zones remain underserved, particularly at the youth- and elderly-dominated periphery. Finally, a substantial share of park polygons was excluded during the manual verification (Section 3.2). This suggests that greenspace inventories used for planning should incorporate a comparable verification step. They should not rely on land-use classification alone.

6.3.1 Analytical and Contextual Scope

The analysis operates at the level of 211 statistical zones, an administrative rather than behaviorally grounded delineation of neighborhoods. This raises the modifiable areal unit problem. It further limits the extent to which zone-level associations can be read as claims about individual residents. The four socioeconomic and demographic predictors are grounded in the inequality literature and data availability. They do not exhaust the dimensions along which disparity could be operationalized. Housing tenure, education and household composition were not available at the statistical zone level. The findings are further bound to Zurich's specific planning context of high overall income, extensive public greenspace investment and strong municipal land-use control. This context differs from the North American contexts that dominate the greenspace inequality literature. The absence of a robust income-accessibility relationship under the Spatial Error Model should accordingly not be generalized to cities with different governance and settlement patterns.

6.4 Future Research

The compiled park dataset of 104 verified parks is augmented with accessibility and characteristics values. It provides a foundation that extends beyond the inequality analysis conducted here. As existing greenspace data sources showed shortcomings in definition and uniformity, this thesis prioritized a transferable verification protocol. Applying that protocol to other Swiss or European cities would test one open question. Is the divergence betweek park, forest and baseline greenness in Zurich a general methodological caution? Or is it a spatial configuration specific to Zurich?

Future work could also extend the amenity-level approach adopted here. This means incorporating condition or quality attributes beyond presence, such as maintenance state or perceived safety. Attributes of the walking environment itself (sidewalk quality, traffic exposure and topography) would also be interesting to investigate. They shape whether a nominally accessible park is realistically reachable and used. These attributes reflect the lived experience of park access. The network-based accessibility measure used in this thesis cannot capture them. They could ideally be validated with resident surveys or on-site audits, addressing the qualitative gap identified here.

Longitudinal data would track both socioeconomic composition and park provision over multiple years, rather than a single cross-section. This would allow the disparity associations found here to be tested for stability over time. This would also be insightful regarding Zurich's population growth and greenspace inventory change. Finally, some predictors were not available at the statistical zone level in this thesis, such as education or household composition. Incorporating them would help establish whether the associations found for youth and elderly residents hold more broadly. This should be tested under a wider set of socioeconomic and demographic indicators.

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Appendix A

Supplementary Material

A.1 Detailed List of Datasets

Table A.1: Detailed dataset specifications.

Dataset	Format	Geometry	CRS	Source
Age Composition	CSV	—	—	(City of Zurich, 2026a)
Baumkataster	GeoPackage	Point	LV95	(Grün Stadt Zürich, 2026a)
Brunnen	GeoPackage	Point	LV95	(City of Zurich, 2026b)
Foreign nationals[a]	CSV	—	—	City of Zurich
Fuss- und Velowegnetz	GeoPackage	Line	LV95	(City of Zurich, 2022)
Grünflächen	GeoPackage	Polygon	LV95	(Grün Stadt Zürich, 2026b)
Median Income[a]	CSV	—	—	City of Zurich (Tax Office)
OpenStreetMap Datasets	Vector (`osmnx`)	Point & Polygon	WGS84	(OpenStreetMap contributors, n.d.)
Sitzbankkataster	GeoPackage	Point	LV95	(Grün Stadt Zürich & Tiefbauamt Zürich, 2024)
Statistical zones	GeoPackage	Polygon	LV95	(City of Zurich, 2026c)
STATPOP[a]	CSV	Point	LV95	Federal Statistical Office
SWISSIMAGE RS	GeoTIFF (raster)	—	LV95	(swisstopo, 2025a)
swissTLM3D	GeoPackage	Line/Polygon	LV95	(swisstopo, 2025b)
Waldareal	GeoPackage	Polygon	LV95	(Canton of Zurich, 2017)
ZüriWC	GeoPackage	Point	LV95	(City of Zurich, 2026d)

[a] Requested directly from the data provider; not publicly available.

A.2 Python Packages

All data processing, spatial analysis and visualization for this thesis were conducted in Python 3.11.15. Table A.2 lists the main packages used, their version and their primary function within the workflow.

Table A.2: Main Python packages used for data processing, spatial analysis and visualization.

Package	Version	Primary Function
contextily	1.7.0	Basemap tiles for context in maps
esda	2.9.0	Exploratory spatial data analysis (Moran's I, Gi*, LISA)
fiona	1.10.1	Reading/writing vector file formats (GeoPackage)
geopandas	1.1.3	Vector geospatial data handling (GeoDataFrames)
libpysal	4.14.1	Spatial weights matrices (Queen contiguity)
mapclassify	2.10.0	Choropleth classification schemes
matplotlib	3.10.9	Static plotting and map visualization
networkx	3.6.1	Graph construction and Dijkstra shortest-path routing
numpy	2.4.4	Numerical array operations
osmnx	2.1.0	Retrieval of OpenStreetMap street/path network data
pandas	3.0.3	Tabular data handling and manipulation
pyogrio	0.12.1	Fast I/O backend for GeoPackage/Shapefile
rasterio	1.4.4	Raster (NDVI tile) I/O and processing
scikit-learn	1.8.0	Standardization / scaling of variables
scipy	1.17.1	Statistical tests, KDE, spatial indexing (cKDTree)
seaborn	0.13.2	Statistical data visualization
shapely	2.1.2	Geometric operations on vector data
spreg	1.9.0	Spatial regression models (OLS, Spatial Error Model)
statsmodels	0.14.6	Statistical modeling (OLS regression)
tqdm	4.67.3	Progress bars for long-running loops

A.3 OpenStreetMap Query

The following OverPass Turbo query was used to retrieve park-related features from OpenStreetMap within the canton of Zurich:

```
[out:json][timeout:60];
{{geocodeArea:Kanton Zurich}}->.searchArea;
(
  way["leisure"="park"](area.searchArea);
  way["leisure"="garden"](area.searchArea);
  way["landuse"="recreation_ground"](area.searchArea);
```

```
  way["landuse"="grass"](area.searchArea);
  relation["leisure"="park"](area.searchArea);
  relation["leisure"="garden"](area.searchArea);
  relation["landuse"="recreation_ground"](area.searchArea);
  relation["landuse"="grass"](area.searchArea);
);
out body;
>;
out skel qt;
```

A.4 Filter by Main Function Keywords

Table A.3: Keywords used to exclude non-park features from the park datasets.

Keyword	Excluded Feature Type
arbeitsintegration	Work integration facilities
bachufer	Stream-side green strips
böschung	Slopes and embankments
botanischer	Botanical gardens
busgarage	Bus garages
depot	Storage depots
familiengarten	Allotment gardens
flussbad	River bathing facilities
freibad	Outdoor swimming pools
friedhof	Cemeteries
hallenbad	Indoor swimming pools
limmatufer	Limmat riverbank strips
OIZ	Municipal IT facilities
parkhaus	Multi-storey car parks
parkplatz	Surface car parks
PSA	Vehicle storage areas
recyclinghof	Recycling facilities
schlachthaus	Slaughterhouse grounds
schul	School grounds
seebad	Lake bathing facilities
sportanlage	Sports grounds
sportzentrum	Sports centres

Continued on next page

Table A.3 continued

Keyword	Excluded Feature Type
stadtspital	Hospital grounds
tennisanlage	Tennis courts
tramdepot	Tram depots
tramstrasse	Tram corridors
turnhalle	Gymnasiums
unterwerk	Electrical substations
VBZ	Public transport facilities
verkehrsschul	Traffic education facilities
werkhof	Municipal service yards
WL	Utility line corridors
WS	Municipal workshops

A.5 Sensitivity Analysis: Distance-Decay Weights

Three alternative distance-decay specifications were tested against the baseline weights $\{0.75, 0.50, 0.25\}$: a steep specification $\{0.90, 0.50, 0.10\}$ emphasizing near-field access, a flat specification $\{0.60, 0.50, 0.40\}$ applying a weaker distance penalty and a near-binary specification $\{1.00, 0.50, 0.10\}$. Spearman rank correlations between the baseline and all alternative specifications exceeded $\rho = 0.97$ (Table A.4), indicating that zone-level accessibility rankings are robust to the choice of decay weights. Results are therefore reported for the baseline specifications only.

Table A.4: Spearman rank correlations between baseline and alternative distance-decay specifications (zone-level park accessibility scores, $n = 211$).

Comparison	ρ	p
Baseline vs. steep	0.973	<0.001
Baseline vs. flat	0.985	<0.001
Baseline vs. binary	0.968	<0.001

A.6 Municipal Greenspace Data

Table A.5: Complete list of land cover types with vegetation classification (Source: Municipal greenspace dataset).

Land Cover Type	English Translation	Category
Beetrosen	Bed roses	Vegetation
Blumenrasen	Flower lawn	Vegetation
Blumenwiese	Wildflower meadow	Vegetation
Bodendecker	Ground cover planting	Vegetation
Dachbegrünung extensiv	Extensive green roof	Vegetation
Formhecke	Formal hedge	Vegetation
Gefäss- und Trogbegrünung im Aussenbereich	Container and trough planting (outdoor)	Vegetation
Gebrauchsrasen	Amenity lawn	Vegetation
Hochstaudenflur	Tall forb community	Vegetation
Mietergarten	Tenant garden	Vegetation
Moorbeet	Bog bed	Vegetation
Parkwald	Park woodland	Vegetation
Ruderalvegetation	Ruderal vegetation	Vegetation
Schotterrasen	Gravel lawn	Vegetation
Sportrasen	Sports turf	Vegetation
Staudenbepflanzung	Perennial planting	Vegetation
Strauchbepflanzung	Shrub planting	Vegetation
Vertikalbegrünung	Vertical greening	Vegetation
Wechselflor	Seasonal bedding	Vegetation
Wildhecke	Wild hedge	Vegetation
Asphalt und Ortbeton	Asphalt and concrete	Non-vegetation
Brunnen, Wasserbecken, Planschbecken	Fountain, pool, paddling pool	Non-vegetation
Chaussierung	Gravel path	Non-vegetation
Fallschutz fest	Fixed impact protection	Non-vegetation
Fallschutz lose	Loose impact protection	Non-vegetation
Gebäude	Building	Non-vegetation
Gewässer fliessend	Flowing water body	Non-vegetation
Gewässer ruhend	Still water body	Non-vegetation
Holz- und Rindenschnitzelbelag (Finnenbahn)	Wood chip / bark surface (Finnish track)	Non-vegetation

Continued on next page

Table A.5 continued

Land Cover Type	English Translation	Category
Holzbelag	Timber decking	Non-vegetation
Kontrolle GSZ	GSZ inspection area	Non-vegetation
Kunststoffrasen unverfüllt	Artificial turf (unfilled)	Non-vegetation
Mauer	Wall	Non-vegetation
Pflasterung und Plattenbeläge (inkl. Rasengitter)	Paving and slabs (incl. grass grid)	Non-vegetation
Sandfläche (Spiel/Sport)	Sand surface (play/sport)	Non-vegetation
Sonstige	Other	Non-vegetation
Tennenbelag	Clay/cinder surface	Non-vegetation
Treppe, Sitzstufe	Steps, seating ledge	Non-vegetation
Trockenmauer	Dry-stone wall	Non-vegetation
Uferverbauung	Bank reinforcement	Non-vegetation

A.7 Final Park Selection

Table A.6: Final park selection (n = 104) with key characteristics.

ID	Park Name	Area (ha)	Benches (per m^2)	Fountains	Toilet	Path density (m/m^2)	Veg. cover (%)
1	Aemtleranlage	1.26	0.002385	Yes	Yes	625.4	79.2
2	Allmend I	21.18	0.000142	Yes	Yes	220.2	94.5
3	Allmend Stettbach	8.89	0.000000	No	No	348.0	97.7
4	Althoosanlage	0.60	0.002323	Yes	No	295.2	93.8
5	Andreaspark	1.21	0.003464	No	No	903.5	85.9
6	Arboretum	3.52	0.002588	Yes	Yes	489.5	72.8
7	Arnold Hünerwadel	0.51	0.001776	Yes	No	1073.4	81.8
8	Artergut	1.01	0.003077	No	Yes	562.8	71.9
9	Auzelg Spielplatz	0.61	0.000000	Yes	No	653.3	100.0
10	Bachwiesenpark	3.10	0.001450	Yes	Yes	481.6	77.4
11	Beckenhof	1.37	0.002401	Yes	Yes	602.4	68.7
12	Belvoirpark	5.18	0.001273	Yes	No	508.6	71.8
13	Bettli-Park	1.90	0.000000	No	No	603.0	49.2
14	Blatterwiese	1.91	0.001464	Yes	Yes	312.3	82.7

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Table A.6 continued

ID	Park Name	Area (ha)	Benches (per m^2)	Fountains	Toilet	Path density (m/m^2)	Veg. cover (%)
15	Bubenholzpark	0.67	0.000000	Yes	No	371.8	48.2
16	Bucheggpark	2.02	0.002479	No	No	619.2	70.5
17	Buchholz	0.92	0.003603	Yes	Yes	478.6	80.8
18	Bullingerhof	2.19	0.002872	Yes	Yes	275.2	69.0
19	Bäckeranlage	1.36	0.003526	Yes	Yes	576.7	64.2
20	Erismannhof	0.54	0.002399	Yes	No	216.2	30.6
21	Freizeitanlage Seebach	2.13	0.002540	Yes	No	913.6	62.2
22	Fritschiwiese	1.36	0.005130	Yes	Yes	393.5	50.6
23	General-Guisan-Quai (Platz)	0.56	0.004484	Yes	No	492.6	2.5
24	Grünzug Am Suteracher	0.51	0.001748	No	No	1193.1	74.8
25	Grünzug Bachwiesen	0.52	0.002694	Yes	No	1339.8	80.7
26	Grünzug Glattwiesen	0.95	0.001693	Yes	No	977.8	82.8
27	Grünzug Riedgraben	0.58	0.002606	Yes	No	2141.1	93.9
28	Grünzug Saatlen/Schörli	2.73	0.002200	Yes	No	766.3	82.9
29	Grünzug Triemlifussweg	1.40	0.001074	Yes	No	790.8	83.4
30	Grünzug Weibelacker	0.52	0.000384	No	No	2140.0	46.7
31	Gänziloohangfuss	3.17	0.000000	No	No	403.3	94.7
32	Hainweg	0.51	0.000000	No	Yes	1081.3	53.1
33	Hambergersteig	0.81	0.000247	No	No	407.4	93.7
34	Hardaupark	1.36	0.001612	Yes	Yes	491.4	42.4
35	Haus Le Corbusier	0.67	0.000599	Yes	Yes	593.5	89.0
36	Heidegraben	1.86	0.002415	Yes	No	456.6	51.5
37	Heiligfeld	1.81	0.002706	Yes	No	710.4	73.9
38	Hohe Promenade	0.54	0.004224	Yes	No	1255.8	39.7
39	Irchelpark	10.90	0.000202	Yes	Yes	447.9	40.8
40	Jabee Park	0.64	0.000000	Yes	No	933.6	41.8

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Table A.6 continued

ID	Park Name	Area (ha)	Benches (per m^2)	Fountains	Toilet	Path density (m/m^2)	Veg. cover (%)
41	Jonas-Furrer-Park	0.60	0.005132	No	No	485.8	90.7
42	Josefwiese	2.07	0.002509	Yes	Yes	665.7	69.1
43	Kanzlei	0.79	0.000255	Yes	Yes	704.3	21.6
44	Kasernenareal	3.90	0.001127	No	Yes	433.1	63.1
45	Klingenpark	0.56	0.002141	Yes	No	531.0	68.6
46	Klopstockwiese	2.55	0.000707	No	Yes	263.9	95.4
47	Kluspark	1.03	0.000485	Yes	No	596.1	70.4
48	Koch-Park	1.02	0.000000	Yes	Yes	432.1	1.8
49	Kollerwiese	1.36	0.002350	Yes	Yes	682.5	86.6
50	Känguruwiese	1.29	0.000622	Yes	No	564.1	88.4
51	Landiwiese	3.92	0.000612	Yes	Yes	426.8	76.2
52	Leutschenpark	1.53	0.000000	Yes	No	99.1	19.8
53	Lindenhof	0.68	0.004987	Yes	No	534.0	11.1
54	Louis-Häfliger-Park	0.70	0.005430	Yes	No	736.1	54.9
55	MFO-Park	0.57	0.010490	No	No	634.3	17.0
56	Mattenhof	1.09	0.000091	No	No	630.8	73.0
57	Mettlenpark	1.00	0.000000	No	No	504.2	86.8
58	Muraltengut	1.66	0.001148	Yes	No	392.5	74.2
59	Mythenquai (Park)	1.15	0.003637	Yes	No	598.1	46.3
60	Navillepark	1.22	0.000000	No	Yes	754.7	61.8
61	Neumünsteranlage	0.90	0.003008	Yes	Yes	583.9	67.7
62	Oberer Letten	0.94	0.000107	No	No	992.9	71.4
63	Oerlikerpark	1.77	0.005313	Yes	Yes	803.9	29.9
64	Opfikerpark	5.98	0.000000	No	Yes	389.8	88.4
65	Park Im Gut	0.62	0.000485	Yes	No	684.9	91.9
66	Park Sihlhölzli	0.84	0.002145	Yes	Yes	711.2	78.8
67	Patumbah-Park	0.76	0.004744	Yes	No	625.2	72.3
68	Pfingstweid	1.38	0.004775	Yes	Yes	519.3	61.3
69	Platzspitz	3.37	0.001956	Yes	Yes	588.6	53.8
70	Pärkli Regensdorf	0.55	0.000000	Yes	No	685.6	69.0
71	Quartierpark Berghalde	1.03	0.001742	Yes	No	410.4	63.7
72	Quartierpark Hirzenbach	1.21	0.002396	Yes	No	423.8	73.1

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Table A.6 continued

ID	Park Name	Area (ha)	Benches (per m^2)	Fountains	Toilet	Path density (m/m^2)	Veg. cover (%)
73	Quartierpark Josef-Areal	0.63	0.005876	No	No	854.0	25.3
74	Quartierpark Schütze	0.91	0.008113	Yes	Yes	383.7	43.7
75	Rechberg	0.55	0.003628	Yes	No	1859.8	43.2
76	Rieterpark	6.18	0.001198	Yes	No	433.6	85.0
77	Rietpark	2.31	0.000000	No	No	558.8	38.0
78	Savera-Areal	1.41	0.001207	Yes	Yes	278.4	71.3
79	Schindlergut	2.43	0.001894	Yes	Yes	685.3	81.8
80	Schärenmooswiese	0.97	0.000620	No	No	405.0	79.7
81	Seeburgpark	1.28	0.000627	No	No	556.8	82.9
82	Seefeldquai	2.74	0.002959	Yes	Yes	567.8	51.1
83	Seefeldwiese	0.57	0.001229	Yes	No	426.4	95.0
84	Sonnenberg	0.63	0.006829	Yes	Yes	1567.4	40.9
85	Spielplatz Holunderweg	0.54	0.002214	No	No	773.6	91.2
86	Stadthausanlage	0.68	0.003828	Yes	Yes	478.5	11.4
87	Steinkluppen	1.10	0.001548	Yes	No	681.5	73.2
88	Stolzewiese	0.81	0.004581	Yes	Yes	720.4	63.1
89	The Hip Dübi Park	0.52	0.000000	No	No	514.3	89.6
90	Turbinenplatz	0.88	0.003420	Yes	No	471.0	18.5
91	Ueberbauung Gruenau	2.15	0.000186	No	No	387.7	99.8
92	Ueberlandpark	3.22	0.000497	Yes	Yes	1400.7	55.4
93	Universitätsspital Park	2.68	0.000821	Yes	No	457.0	49.4
94	Utoquai	1.54	0.012136	Yes	Yes	800.1	22.1
95	Villa Bleuler	0.57	0.000175	Yes	No	1305.5	75.9
96	Villa Hohenbühl	0.62	0.000487	Yes	No	863.8	71.7
97	Villa Schönberg	0.62	0.000974	Yes	Yes	618.4	73.0
98	Wahlenpark	1.26	0.003264	Yes	Yes	427.2	57.5
99	Waid	1.20	0.003343	Yes	No	946.7	77.5
100	Waldgarten	0.87	0.002772	Yes	No	539.2	77.0
101	Werdinsel	5.28	0.000227	Yes	Yes	256.9	89.9
102	Wipkingerpark	1.20	0.001757	Yes	Yes	580.6	55.2
103	Wolfbachtobel	0.66	0.002434	Yes	No	1233.2	74.0

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Table A.6 continued

ID	Park Name	Area (ha)	Benches (per m^2)	Fountains	Toilet	Path density (m/m^2)	Veg. cover (%)
104	Zürichhorn	4.43	0.000948	Yes	Yes	342.7	63.6

A.8 100%-Stacked-Area Charts

The 100%-stacked-area charts in Figure 4.16, Figure 4.18 and Figure 4.19 show how the socioeconomic and demographic composition of statistical zones shifts across the range of a greenspace outcome (park access, forest access and baseline greenness). Each figure contains one panel per predictor (median income, share of foreign nationals, share of elderly residents and share of youth).

Within each panel, predictor values are first checked for outliers using Tukey's rule. Zones with values below $Q1 - 1.5 \times IQR$ or above $Q3 + 1.5 \times IQR$ of that predictor are excluded from the panel before further processing. This is why the number of zones (n, reported in the panel title) varies slightly between panel of the same figure. The remaining zones are split into quartiles of the predictor (Q1–Q4) using rank-based binning (`pandas.qcut`).

Within each quartile, a Gaussian kernel density estimate (bandwidth factor 0.5, `scipy.stats.gaussian_kde`) is fitted to the outcome scores of the zones in that quartile and evaluated on an evenly spaced grid of 400 points along the x-axis. At every grid point x, the four quartile densities are rescaled to sum to 100 percent and stacked cumulatively (Q1 at the bottom, Q4 at the top). This produces the smoothed 100%-stacked area. The x-axis itself is truncated at the outcome variable's own upper Tukey fence ($Q3 + 1.5 \times IQR$ of the outcome, e.g. 11.96 for the park access score) to keep the display legible. That truncation only limits the plotted range and does not remove zones from the underlying density estimate. Because the bands are density-based rather than raw counts, they read as smooth curves rather than stepped histograms. The charts are therefore an exploratory, visual complement the Spearman correlations and regression results reported alongside them, not a statistical test in their own right.

A.9 Park Characteristic Statistics

Table A.7: Bivariate Local Moran's I (LISA) cluster statistics for park characteristic scores and socioeconomic/demographic predictors (n = 211)

Characteristic	Predictor	I_{BV}	%HH	%LH	%LL	%HL	%NS
Bench density	Median income	0.060	6.6	10.9	11.4	5.7	65.4
	Foreign nationals	0.064	8.1	9.5	10.4	6.6	65.4
	Elderly (65+)	−0.041	7.6	10.0	5.7	11.4	65.4
	Youth (0–15)	−0.287**	7.1	10.4	3.8	13.3	65.4
Path density	Median income	−0.027	8.5	11.8	9.0	6.2	64.5
	Foreign nationals	0.027	9.0	11.4	8.5	6.6	64.5
	Elderly (65+)	0.045	12.8	7.6	5.7	9.5	64.5
	Youth (0–15)	−0.128**	11.4	9.0	2.4	12.8	64.5
Fountain availability	Median income	0.104**	9.0	12.8	8.5	3.3	66.4
	Foreign nationals	−0.048	7.6	14.2	5.2	6.6	66.4
	Elderly (65+)	0.000	11.8	10.0	5.2	6.6	66.4
	Youth (0–15)	−0.180***	10.4	11.4	2.8	9.0	66.4
Vegetation cover	Median income	−0.076	4.7	9.0	5.2	4.3	76.8
	Foreign nationals	−0.028	4.7	9.0	4.7	4.7	76.8
	Elderly (65+)	−0.012	8.5	5.2	2.8	6.6	76.8
	Youth (0–15)	0.207***	10.0	3.8	5.7	3.8	76.8
Toilet availability	Median income	0.137**	8.1	12.3	14.7	4.3	60.7
	Foreign nationals	0.053	13.3	7.1	9.0	10.0	60.7
	Elderly (65+)	−0.230***	3.3	17.1	10.4	8.5	60.7
	Youth (0–15)	−0.289***	4.7	15.6	3.8	15.2	60.7

Note. I_{BV} = global bivariate Moran's I; ** $p < 0.01$, *** $p < 0.001$. HH = High-High, LH = Low-High, LL = Low-Low, HL = High-Low (primary indicator of spatial deprivation), NS = Not significant. Percentages are row-wise shares of zones (n = 211) assigned to each local cluster type.

Appendix B

Personal Declaration

I hereby declare that the submitted thesis results from my own independent work. All external sources are explicitly acknowledged in the thesis.

I further acknowledge that AI has been used in this thesis as follows:

- Brainstorming with Claude (Sonnet 4.6 & 5)
- Summaries and explanations of research literature with Claude (Sonnet 4.6 & 5)
- Translation and finding synonyms with Linguee
- Stylistic improvement with Linguee and Claude (Sonnet 4.6 & 5)
- Help with code generation and thesis documentation (in Overleaf) with Claude (Sonnet 4.6 & 5)

All textual input by AI has been checked and adjusted by me, the author of this thesis. I take full responsibility of the text.

Zurich, 27.08.2026



Sonja Rigoni