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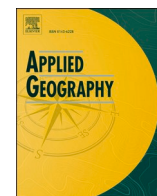
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Assessing gendered accessibility inequalities to urban facilities among refugees: A 3SFCA method

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ABSTRACT

Spatial accessibility to urban facilities has been extensively examined in the literature. However, gendered disparities in spatial access remain underexplored, particularly among refugee populations. This research assesses the spatial accessibility of four key urban facilities – education, health, green, and religious – in Konya, Türkiye, using the Three-Step Floating Catchment Area (3SFCA) method. The research quantifies spatial-structural inequalities arising from the distribution of facilities and refugee settlements, independent of behavioural variations. Accessibility scores were further evaluated using Lorenz curves and Gini coefficients to examine distributional inequalities.

Findings reveal consistent gender-based spatial disparities. Men exhibit higher accessibility scores across all facility types compared to women, with the greatest inequalities in health and green areas. Gini coefficients indicate that women experience higher within-group spatial inequality, revealing compound disadvantage. This study offers two significant contributions: (1) an empirical application of spatial accessibility methods (3SFCA, Lorenz curves, and Gini coefficients) to assess gendered refugee accessibility, and (2) evidence quantifying baseline spatial-structural inequalities in urban service provision arising from the spatial distribution of facilities and refugee settlements. The results underscore an urgent need for gender-sensitive urban planning and equitable service distribution to address accessibility gaps.

1. Introduction

Conflicts in urban areas disrupt the social and economic fabric, often forcing people to abandon their safe living environments. Such challenges typically destroy the urban infrastructure and make essential services (i.e., transportation, healthcare, education, and green areas) inaccessible, leaving urban residents in unsafe conditions. The threat to personal safety is a key factor in individuals' and families' decisions to seek more secure and stable living conditions, usually in foreign countries. For those forced to migrate, the search for safety often leads them to overcrowded urban centres in host countries, where resources are already limited. Refugee populations, particularly women (Özkazanc, 2021), face multiple difficulties in accessing urban services – a spatial accessibility challenge shaped by urban form, service distribution, and socio-economic marginalisation. Addressing accessibility challenges requires understanding the intersection of displacement, gender, and urban inequality to ensure just access for all residents, especially the most vulnerable.

1.1. Spatial accessibility and gendered refugee populations

Urban accessibility is the spatial ease with which individuals can access essential facilities and services (Cohen, 2020) and it serves as a cornerstone for equitable and inclusive urban development (Talen, 2001). Yet accessibility remains unevenly distributed, particularly among vulnerable populations. Gender-based inequalities persist in urban contexts, manifesting spatially through restricted access to opportunities and services (Lucas & Jones, 2012; Xu et al., 2020). Spatial planning and service distribution often fail to account for gendered differences in needs and constraints, resulting in systematic disadvantages for women in accessing education, health, and employment (Pourhashem et al., 2022). These patterns intensify for refugee populations, where spatial marginalisation intersects with displacement and socioeconomic vulnerability.

Refugees face multiple spatial barriers due to low literacy rates, language barriers, and limited income (Barajas, 2021; Özkazanc, 2021). Most forced migrants arrive without employment or income sources

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(Enderle, 2024), concentrating them in low-cost, spatially segregated neighbourhoods with limited-service provision. This residential segregation restricts effective access to essential urban facilities (Allen et al., 2021; Clark & Wang, 2010; Farber et al., 2018).

For refugee women specifically, spatial access is further constrained by the intersection of gender norms and displacement. In patriarchal contexts, women's spatial mobility is often restricted to caregiving-related activities (Çag & Özkazanç, 2025; Fenster, 2005), limiting access to broader urban opportunities. Cultural and religious norms further restrict independent spatial mobility (Chowdhry, 2014; White, 2017), creating compounded spatial disadvantages in access to urban services (Golizadeh et al., 2023; Smith et al., 2022; Özkazanç, 2024).

While behavioural factors shape these access patterns, understanding the underlying spatial-structural inequalities remains critical. Existing research has extensively documented experiential and behavioural barriers, but has given less attention to how the spatial distribution of services and settlements itself creates differential accessibility independent of behavioural variations. This spatial dimension provides essential baseline knowledge for evidence-based urban planning interventions.

1.2. Measuring spatial-structural inequalities: the 3SFCA method

Quantifying such spatial-structural inequalities requires methods that isolate service distribution from behavioural factors, for which the Three-Step Floating Catchment Area (3SFCA) method (Wan et al., 2012) is widely employed. This gravity-based approach advances earlier floating catchment methods (W. Luo & Wang, 2003; Radke & Mu, 2000) by formulating catchment areas as dynamic variables and adopting Gaussian distance decay functions to capture spatial competition among facilities. This methodology integrates the floating catchment area framework with a probabilistic modelling approach (Fang et al., 2025). From a spatial perspective, it provides a comprehensive analysis by considering both the supply-demand balance and the geographical distribution of facilities and populations, allowing for a more accurate assessment of service equity and accessibility patterns.

In recent studies, the 3SFCA method has been employed as an established approach for evaluating the accessibility of various urban facilities (Table S1), such as educational facilities (Rekha et al., 2017; Zhang et al., 2023), health facilities (Dumedah et al., 2023; Gómez et al., 2018; Shen et al., 2021), green areas (Fang et al., 2025; Ye et al., 2024). While most research has focused on residents as the primary sample group, several studies have examined different populations. In their respective studies, Han et al. (2023) and Deng and Ning (2024) employed the 3SFCA method with varying age groups, utilising the Gini index to assess the inequity of accessibility. Chen and Yeh (2019), and Shatnawi et al. (2022) analysed the accessibility of healthcare facilities in different income groups. Furthermore, studies have been conducted to investigate residents' access to service areas using various modes of urban transportation (Fang et al., 2025; Gan et al., 2024; Liang et al., 2023).

1.3. Knowledge gap and contribution

Although the 3SFCA method has been widely applied to assess accessibility across demographic subgroups based on income and age (Cao et al., 2022; Dumedah et al., 2023), gendered accessibility among refugee populations remains unexplored, representing an important research gap in the literature. Furthermore, studies of multi-facility accessibility (C. Li & Wang, 2024; Zhang et al., 2023) have primarily focused on general urban residents rather than vulnerable displaced populations.

Existing research on refugees has predominantly examined experiential and behavioural aspects of urban access, including transportation challenges, mode choice constraints, and mobility barriers (P. S. Bose, 2014; Smart, 2015). While these behavioural dimensions are crucial,

the spatial-structural foundation underlying these inequalities remains underexplored. Specifically, there is a limited understanding of how the spatial distribution of services and refugee settlements itself creates differential accessibility patterns, independent of behavioural variations.

This study addresses a core question: To what extent does the spatial distribution of urban services create gendered accessibility inequalities among refugee populations? Examining this question in Konya, Türkiye, a city hosting a significant Syrian refugee population, the research focuses on four key urban facilities (education, health, green areas, and religious spaces) to document these inequalities and inform policy interventions. The research offers two primary contributions. First, it provides an empirical application of the 3SFCA method to gendered refugee accessibility, an approach not previously applied to this population. Second, it adopts a spatial configuration framework measuring how the distribution of urban services creates accessibility inequalities. By employing uniform travel assumptions across genders, this study establishes a baseline measure of spatial-structural inequality embedded in urban form, revealing the minimum disparity arising from spatial planning decisions alone. The integration of facility-specific accessibility scores with distributional inequality measures (Gini/Lorenz) enables simultaneous assessment of both magnitude and equity of spatial access disparities.

The remainder of this paper is structured as follows. Section 2 presents the methodology, detailing data collection, the 3SFCA implementation, and analytical approaches, including the Lorenz curves and Gini coefficients. Section 3 presents results, emphasizing spatial and gender-based disparities in access to four urban facilities. Section 4 discusses the broader implications, linking findings to the theoretical foundation and addressing limitations. Finally, Section 5 synthesizes the findings and reflects on potential applications of the analytical framework.

2. Methodology

2.1. Study area

Konya, located in the central region of Türkiye, is the largest province in the country, encompassing an area of 38,873 km². With a population of around 2.3 million, Konya is one of the most populous provinces in Türkiye, according to the latest census data (Turk Stat, 2023). This study focuses on 96 neighbourhoods across 3 central districts, covering a total area of 6585 km², within the broader provincial boundary. The term neighbourhood refers to the smallest official administrative unit used in Türkiye's urban governance and statistical reporting system. Within the study area, the built-up urban fabric covers 205 km², of which green areas account for the largest proportion at 4% (8.16 km²), followed by educational facilities (elementary school, secondary school, high school) at 1.1% (2.1 km²), religious facilities (mosques) at 0.66% (1.37 km²), and health facilities (community health centres, university, and city hospitals) at 0.51% (1.06 km²).

Konya provides a relevant case study for examining these dynamics. It hosts a significant refugee population while exemplifying the spatial and social complexities of urban accessibility. In Konya, refugees systematically experience limited access to essential services, deepening their vulnerability and socio-economic exclusion. A demographic analysis of the study area reveals that in 2011, at the onset of the Syrian civil war, male refugees constituted 0.26% of the total male population (1386 individuals), while female refugees comprised 0.21% of the total female population (1135 individuals). By 2023, these proportions had increased to 1.03% for males (7216 individuals) and 0.93% for females (6681 individuals) (Turk Stat, 2023). In terms of geography, the majority of refugees are concentrated in the city centre, within the built-up area. The principal factor influencing this settlement pattern is the relatively low rental prices and the lower quality of housing in the central and surrounding residential areas.

2.2. Study data

To analyse spatial accessibility patterns and gendered inequalities, this study integrated multi-source spatial and non-spatial urban data, following the overall workflow summarised in Fig. 1. Before merging and analysing these datasets, a normalisation strategy was applied to ensure comparability across variables. Two types of normalisations were used for different analytical purposes. Z-score normalisation was employed for statistical analyses (descriptive comparisons), centring variables around their mean and scaling by standard deviation. In addition, min–max normalisation was applied to the distribution of male and female accessibility scores for spatial mapping and Lorenz curve plotting. Gini coefficients, by contrast, were computed on raw accessibility scores as the Gini index does not require prior normalisation. By rescaling all accessibility scores to a common range between 0 and 1, this approach preserves absolute accessibility differences between genders while enhancing the interpretability and visual comparability of spatial inequalities across neighbourhoods. The datasets used in the study were grouped into three categories:

- (1) **Socio-demographic structure:** Refugee population data was acquired from a local NGO (Elbir Charity and Solidarity Association) in Konya, which conducts systematic registration and spatial mapping of refugees accessing their services in collaboration with the UN Refugee Agency (UNHCR). The dataset comprised age, gender, address, and nationality information about 2889 refugees, selected through the NGO's internal random sampling procedure from among its registered members, who are drawn from the most disadvantaged groups based on criteria including income, health status, employment, and household composition. The NGO database records gender using binary categories (male and female), with no separate identification or data entry for non-binary individuals. Notably, the spatial distribution of male and female refugees across neighbourhoods differs systematically, with female refugees outnumbering males in most central areas (Fig. 2). This differential concentration forms the structural basis for the gendered accessibility disparities documented in this study.
- (2) **Points of Interest (POI):** Four facility types (148 health, 984 religious, 328 education, and 1216 green areas) were selected (Fig. 2, Table 1). POI data were obtained from the Open Data Platform of Konya Metropolitan Municipality (<https://acikveri.konya.bel.tr/en>). Student-teacher ratios for schools were obtained from the Ministry of National Education (<https://www.me.b.gov.tr/>).
- (3) **Transportation infrastructure:** The road network data were obtained from OpenStreetMap (<https://www.openstreetmap.org>). Using ArcGIS Pro, the origin-destination cost matrices (Ye et al., 2024) calculated shortest travel times between residents and facilities.

2.3. 3SFCA method for assessing multi-facility urban accessibility

The 3SFCA method is employed to compute accessibility scores for four urban facilities: green areas, educational facilities, health facilities, and religious facilities. Accordingly, as the first step, the Gaussian function (G) is operationalised for the modified distance impedance coefficient:

$$G(t_{ij}, t_0) = \begin{cases} 1, & \text{if } t_{ij} \leq t_0^w \\ e^{-\left(\frac{1}{2}\right) \times \left(\frac{t_{ij}}{t_0}\right)^2} - e^{-\left(\frac{1}{2}\right)}, & \text{if } t_{ij} > t_0^w \text{ and } t_{ij} \leq t_0 \\ \frac{1}{1 - e^{-\left(\frac{1}{2}\right)}}, & \text{if } t_{ij} > t_0 \end{cases} \quad (1)$$

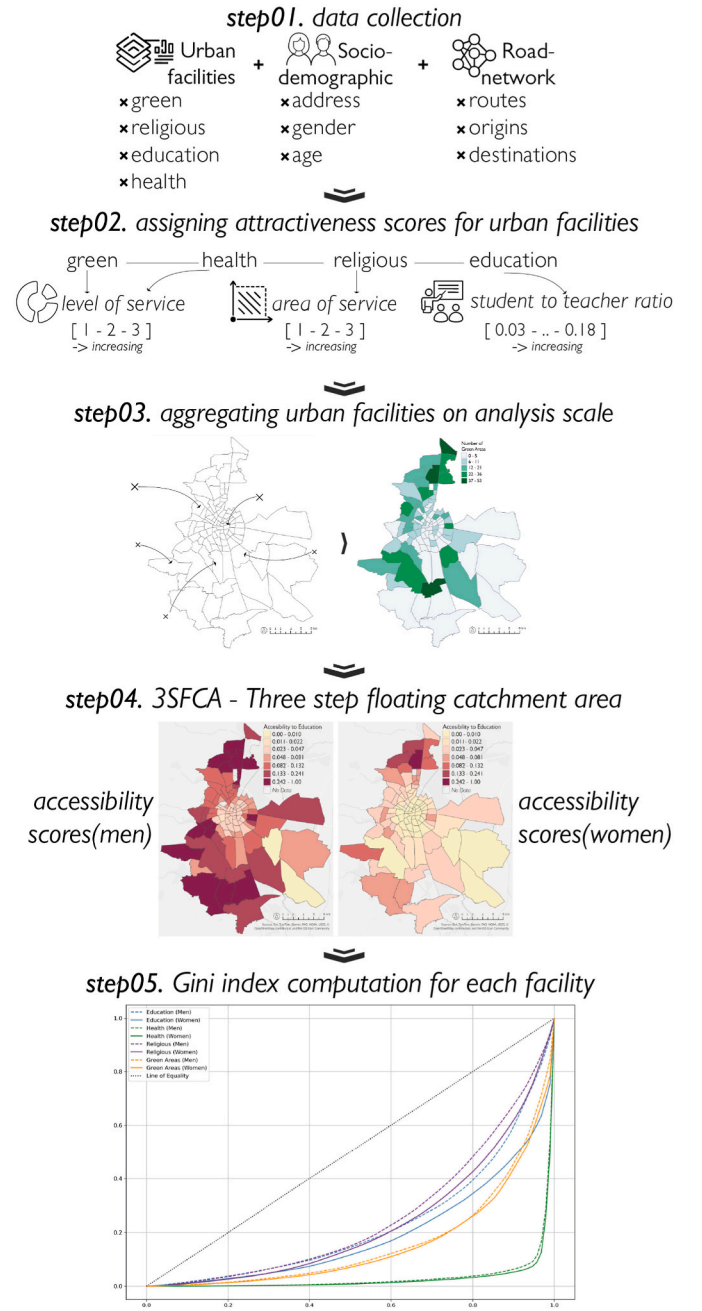


Fig. 1. General flow and the steps of the research.

Here, t_{ij} is the travel time between i and j by walking, and t_0 denotes the maximum catchment threshold travel time from j . In the research, t_0 was established at 30 min for walking, based on findings from prior studies that identified this duration as the psychological limit for any travel method, including walking (Huang et al., 2021). For each facility type, a corresponding maximum time threshold t_0^w was defined based on Türkiye's National Spatial Planning Legislation, as shown in Table 1 (i.e., 7.5 min for green areas and health facilities, 11.2 min for educational facilities, and 4.5 min for religious facilities). These were calculated assuming a uniform walking speed of 4 km/h (Liang et al., 2023). In the model, the Gaussian decay function $G(t_{ij}, t_0)$ is applied to all trips within the 30-min catchment. The facility-specific threshold t_0^w defines a local zone of full accessibility: trips with $t_{ij} \leq t_0^w$ receive full weight ($G = 1$), while trips with $t_0^w < t_{ij} \leq t_0$ experience distance decay according to the Gaussian function. Trips exceeding the global threshold ($t_{ij} > t_0$) are

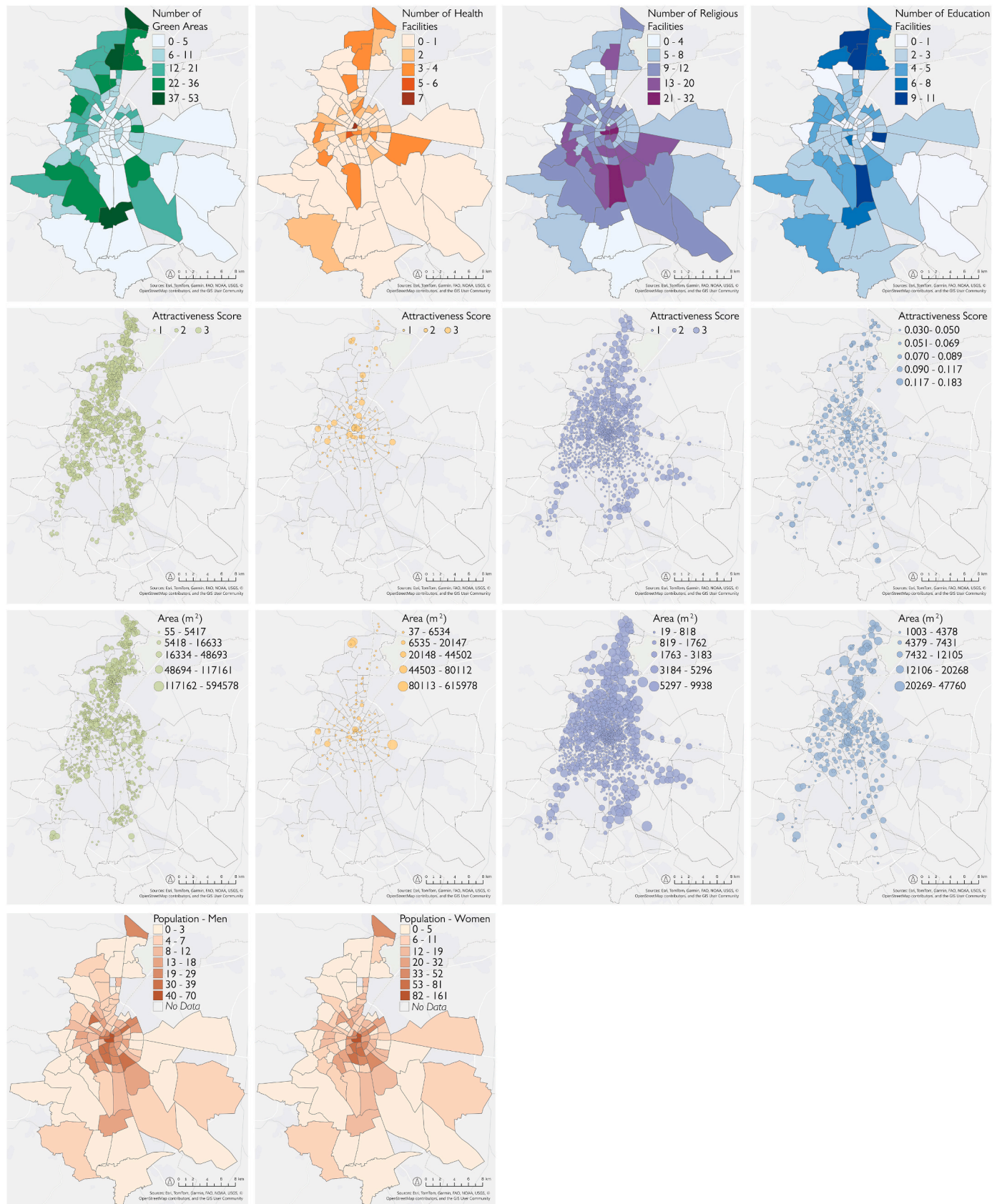


Fig. 2. Spatial distribution of urban facilities (above), attractiveness scores (middle-above), areas (middle-below), and refugee population distribution (below).

Table 1
Attractiveness factors and threshold distances for each POI.

POI	Type of POI	Attractiveness factor	Standard distances ^a	Threshold time (minutes) ^b
Health	Neighbourhood health centre	Level of service	500	7.5
	District hospital			
	City hospital			
Education	Elementary school	The student-teacher ratio for each school	750	11.2
	Secondary school			
	High school			
Green	Playground	Level of service	500	7.5
	Green areas			
Religious	Community Park	Size of mosques	300	4.5
	Mosque			

^a Distances are based on the Türkiye Spatial Planning Legislation.

^b Threshold times are calculated by setting 4 km/h as a standard walking speed.

assigned zero accessibility. This dual-threshold design integrates normative planning expectations (facility-specific thresholds) with behavioural temporal constraints (30-min limit), enabling us to measure deviations from policy-defined ideal accessibility.

Building on the improved 3SFCA approach (Liang et al., 2023), we employed the gravity-based Huff model (J. Luo, 2014) to calculate facility selection probabilities based on spatial competition and attractiveness. The model allows for the calculation of the probability that a resident from location i will visit location:

$$Prob_{ij} = \frac{M_j G(t_{ij}, t_0)}{\sum_{k \in \{t_{ik} \leq t_0\}} M_k G(t_{ik}, t_0)} \quad (2)$$

where M_j is the attractiveness of facility j ; k denotes all facilities accessible from location i within the threshold t_0 . The numerator represents the distance-decayed attractiveness of facility, while the denominator sums the distance-decayed attractiveness of all alternative facilities competing for selection from location i . This probabilistic framework ensures that a facility's selection probability depends not only on its own attractiveness and proximity, but also on the relative attractiveness of competing facilities within the resident's catchment area.

M_j represents the attractiveness of facility j , operationalised through measurable facility characteristics that proxy service capacity and quality. Specifically, this factor is measured using parameters, such as facility size, service capacity and level of service, following established approaches in accessibility modeling (C. Li & Wang, 2024; Zhang et al., 2023). For healthcare facilities, three levels of service (LoS) were defined based on facility type following the National Regulation of Health Service Providers for Türkiye: neighbourhood health centres (LoS = 1), district hospitals (LoS = 2), and city hospitals (LoS = 3). Similarly, green areas were classified into three LoS categories based on Türkiye's Spatial Planning Legislation: playgrounds (LoS = 1), green areas (LoS = 2), and community parks (LoS = 3). Religious facilities were assigned ordinal values (1-3) based on mosque size (floor area in m²), with larger mosques receiving higher scores. For education, the student-to-teacher ratio for each school was used directly as a continuous attractiveness measure (Fig. 2, Table 1).

In the second step (Equation (3)), the catchment area for the facility j was defined by identifying all residential locations (i) within threshold t_0 . The provider-to-population ratio (R_j) was calculated to quantify the supply (i.e., service capacity) in relation to the demand (i.e., population) within the facility's catchment.

$$R_j = \frac{S_j}{\sum_{i \in \{t_{ij} \leq t_0\}} Prob_{ij} P_i} \quad (3)$$

where S_j is the service capacity of j , measured using facility-specific metrics as described for M_j in Equation (2). Here i denotes all the residential locations within the catchment of the facility j and P_i represents the gender-specific refugee population at the location i .

In the third step (Equation (4)), the provider-to-population ratios (R_j) were weighted using G and $Prob_{ij}$, and subsequently summed to estimate spatial accessibility (A_i) at location i . It measures the overall accessibility of the population at the location i , considering both the supply capacity of service providers and the spatial distribution of demand.

$$A_i = \sum_{j \in \{t_{ij} \leq t_0\}} Prob_{ij} R_j G(t_{ij}, t_0) \quad (4)$$

where j represents all facilities accessible from the location i within the threshold t_0 . This aggregated measure captures the overall accessibility opportunities available to residents at the location i , considering both the supply capacity of service providers (R_j), the probability of facility selection based on spatial competition ($Prob_{ij}$), and the spatial penalty of distance (G).

Uniform behavioural parameters (walking mode, 4 km/h speed, Table 1) are employed across genders to isolate spatial-structural inequality from behavioural variations, enabling measurement of inequalities embedded in urban form and service distribution independent of individual mobility behaviour. This approach provides a conservative baseline measure, as real-world disparities likely exceed our estimates when accounting for additional mobility constraints women face (Liang et al., 2023).

Additionally, to empirically identify the mechanistic source of observed gender accessibility gaps, Spearman rank correlations were computed between the male-to-female refugee ratio and neighbourhood-level facility counts. Spearman's rank correlation was employed, given the non-normal distribution of both facility counts and refugee population figures across neighbourhoods. This analysis tests whether facility distribution is spatially independent of refugee gender composition, enabling distinction between supply-side and demand-side drivers of observed accessibility disparities. Then, Wilcoxon signed-rank tests were also conducted for each facility type to assess whether the observed gender differences in accessibility scores are statistically significant at the neighbourhood level. This non-parametric paired test was selected as men's and women's accessibility scores are measured at the same 96 neighbourhoods, and given the right-skewed distribution of accessibility scores, parametric alternatives such as the paired t -test are not appropriate. Finally, to assess the robustness of the inequality results to the choice of distance thresholds, a sensitivity analysis was performed by varying the facility-specific thresholds by $\pm 25\%$ and $\pm 50\%$ of their base values. For each scenario, the full 3SFCA pipeline was recomputed, and Gini coefficients were recalculated to evaluate whether the magnitude and relative ranking of spatial inequalities were sensitive to threshold selection.

2.4. Gini Index and Lorenz Curve for measuring distributional inequality

To assess gendered spatial inequalities in accessibility, this study employed the Gini Index and Lorenz Curve, widely used measures of distributional equity in spatial and economic geography. The Gini Index (Gini, 1912) quantifies statistical dispersion within a distribution, yielding values from 0 (perfect equality) to 1 (perfect inequality). The Lorenz Curve (Lorenz, 1905) provides the graphical foundation, plotting cumulative accessibility shares against cumulative population proportions. Greater deviation below the 45° equality line indicates higher inequality (Martin & Conway, 2025). Mathematically, the Gini Index is defined as:

$$Gini\ index = \frac{A}{A + B} \quad (5)$$

where A denotes the area between the Lorenz curve and the equality line, and B indicates the area under the Lorenz curve. Lorenz curves were computed for each facility type, separately for men and women, based on raw accessibility scores across neighbourhoods. Gini values enable comparison of spatial access inequality between genders.

3. Results

3.1. Urban facility accessibility scores

Accessibility scores reveal consistent gendered disparities across all four facility types, with men exhibiting higher values than women (Table 2). In the 3SFCA framework, a score of zero indicates the absence of accessible facilities within the catchment area, while higher scores reflect greater provider-to-population ratios. Though these scores do not support strictly proportional interpretations, the magnitude of the difference points to a substantively meaningful gap in spatial service coverage. In this manner, the disparity is most pronounced for health facilities, where men's mean accessibility score (1.40) substantially exceeds that of women (0.66). However, the highly right-skewed distribution of health scores, reflected in near-identical medians of 0.05 and 0.04 for men and women respectively, indicates that this gap is largely driven by a small number of neighbourhoods adjacent to major hospitals, while the typical neighbourhood experiences near-zero and near-equal access for both genders. For green areas, both mean and median scores reveal a consistent gender gap: men's mean (1.34) and median (0.52) exceed women's mean (1.01) and median (0.35), suggesting that the disadvantage for women is not confined to outlier neighbourhoods but reflects a broader spatial pattern. Education shows a similar though more modest directional pattern, with men's mean (1.28) and median (0.68) outperforming women's mean (1.08) and median (0.50). Religious facilities exhibit the smallest gender difference, with men's mean (0.72) and median (0.42) slightly exceeding women's mean (0.56) and median (0.31), consistent with the more equitable spatial distribution of mosques documented in the spatial analysis.

Beyond mean differences, spatial analysis of normalised accessibility scores (0-1 range) depicts distinct clusters of high and low accessibility zones across the study area, with marked spatial differentiation between genders.

Spatial analysis shows distinct yet complementary accessibility patterns for male refugees across the four facility types. Education (Fig. 3) and green area (Fig. 4) accessibility share a broadly similar geography, with high-accessibility zones concentrated in the northern and southwestern peripheries and low-accessibility zones dominating the central urban core. Health facility accessibility departs sharply from this pattern. Health facilities cluster in three discrete nodes rather than peripheral dispersion: an eastern core cluster, a western periphery cluster, and a northern periphery cluster (Fig. 5), each anchored by major hospital infrastructure. Of all facility types, religious facilities offer men the broadest and most continuous spatial coverage, with high-accessibility zones spanning southwestern, southeastern, and northern clusters, and moderate-accessibility zones extending relatively uninterrupted across western and northern areas (Fig. 6).

For female refugees, accessibility is markedly more constrained and spatially fragmented across all four facility types. Education and green area high-accessibility zones, which for men span broad peripheral bands, shrink to small, isolated northern clusters for women, while low accessibility extends across the entire urban centre, southeastern, and in the case of green areas, eastern and southern areas as well. Health accessibility follows a similarly peripheral logic, though women's highest values shift toward northern periphery neighbourhoods rather than the eastern cluster that dominates for men, with widespread low accessibility persisting across the central core for both genders. Religious facilities present the relatively most accessible conditions for women, yet even here, high-accessibility zones are noticeably smaller and more fragmented compared to men, and moderate zones, which appear with some continuity for men, emerge only in scattered fragments for women.

Taken together, these patterns reveal a consistent and systematic spatial dynamic: male refugees benefit from broader, more continuous high-accessibility zones distributed across the northern and southwestern peripheries, while female refugees are largely confined to smaller, fragmented clusters within similar geographic bands. The central urban core presents low accessibility for both genders across all facility types, yet this shared disadvantage falls more heavily on women, whose high-accessibility zones are consistently smaller and whose low-accessibility zones extend further into the urban fabric. Among the four facility types, religious facilities stand out as the most spatially equitable, benefiting from high density and short threshold distances, while health and green areas exhibit the sharpest and most spatially pronounced gender contrasts.

Based on the Spearman rank correlation results in 96 neighbourhoods, no statistically significant association was found for any facility type (Table 3), with results consistent across both male-to-female ratio and women's proportion as predictors. These findings confirm that facility distribution in Konya is spatially independent of refugee gender composition. Since uniform behavioural parameters are applied across genders, the entirety of the observed accessibility gap follows by construction, from the differential spatial distribution of male and female refugees across neighbourhoods. The Spearman analysis confirms that facility allocation is gender-neutral, establishing differential population concentration as the sole mechanistic source of the observed disparities.

To further assess whether the observed gender differences are statistically distinguishable at the neighbourhood level, Wilcoxon signed-rank tests were conducted for each facility type (Table 4). The results confirm that men's accessibility scores are statistically significantly higher than women's across all four facility types ($p < 0.001$), placing the central finding on firm inferential footing. The consistency of this result across all facility types, despite the highly skewed distributions and the varying magnitude of mean differences documented in Table 2, reinforces that the gender gap is a systematic spatial pattern rather than an artefact of a few outlier neighbourhoods.

3.2. Gini Index results

Gini coefficients reveal distinct within-group spatial inequality patterns (Table 5). Women exhibit consistently higher inequality across all

Table 2
Descriptive statistics of the accessibility scores for each urban facility.

Gender	Facility	Count	Mean	Standard Deviation	Min	Max	Median
Men	Religion	96.0	0.72	0.72	0.0	3.92	0.42
	Health	96.0	1.40	7.87	0.0	68.60	0.05
	Education	96.0	1.28	1.54	0.0	8.53	0.68
	Green	96.0	1.34	2.54	0.0	19.50	0.52
Women	Religion	96.0	0.56	0.63	0.0	3.08	0.31
	Health	96.0	0.66	3.49	0.0	29.55	0.04
	Education	96.0	1.08	2.67	0.09	25.20	0.50
	Green	96.0	1.01	2.29	0.0	20.17	0.35

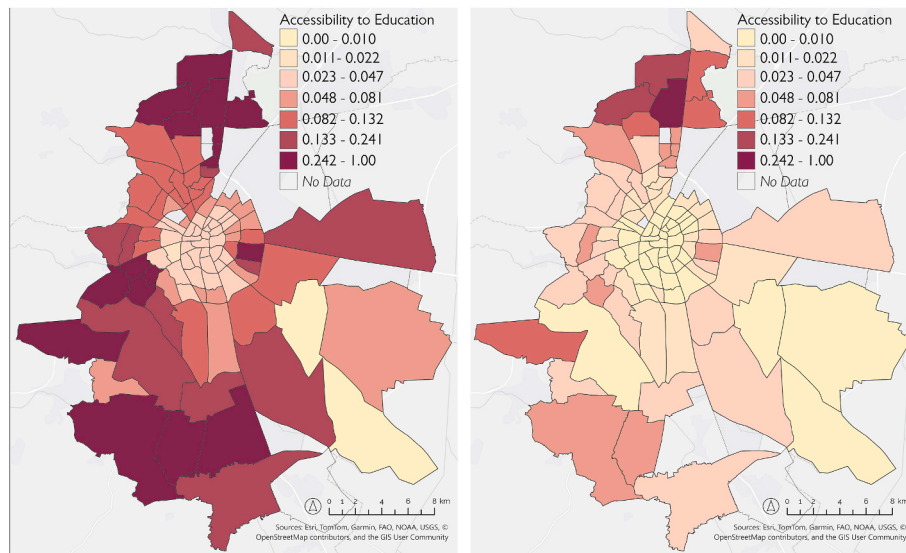


Fig. 3. Accessibility for men (left) and women (right) to education facilities.

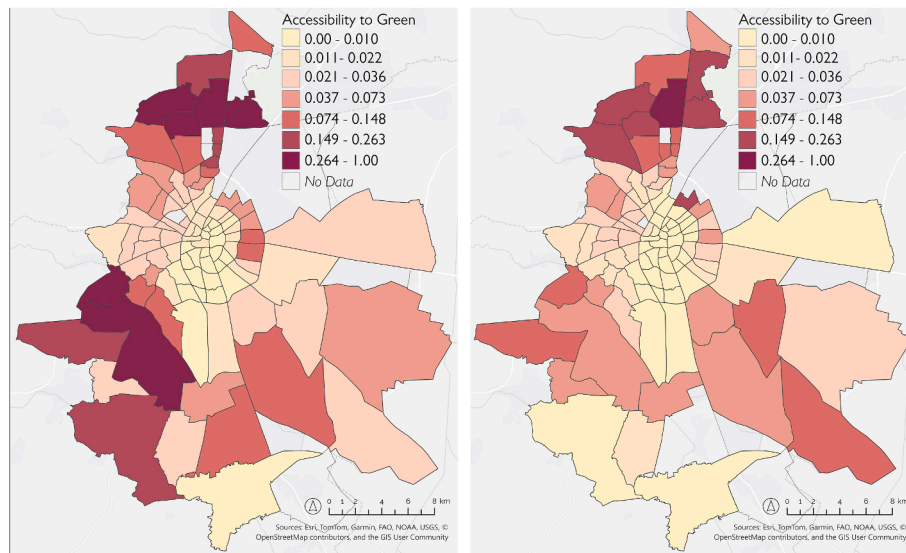


Fig. 4. Accessibility for men (left) and women (right) to green areas. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

facility types (Gini 0.53-0.94) compared to men (0.49-0.92), indicating greater spatial polarization among female refugees. For both genders, inequality peaks in health facilities (men 0.92, women 0.94), reflecting the highly concentrated spatial distribution of hospitals, while religious facilities show the lowest inequality (men 0.49, women 0.53). These findings illustrate compound disadvantage for refugee women, characterized by both lower mean accessibility and more unequal spatial distribution of opportunities.

To assess the robustness of these inequality patterns to threshold selection, a sensitivity analysis was conducted by varying the facility-specific distance thresholds by $\pm 25\%$ and $\pm 50\%$ of their base values, recomputing the full 3SFCA pipeline for each scenario (Table 5). Gini coefficients remain essentially stable across all scenarios, varying by no more than 0.01 in nearly all cases, and the pattern of women experiencing higher within-group inequality than men is preserved across every facility type and threshold scenario. This stability indicates that the observed inequality patterns reflect the underlying spatial configuration of facilities and refugee settlements rather than the specific

threshold values adopted.

Lorenz curves visually reinforce these patterns (Fig. 7). Women's curves (continuous lines) consistently deviate further from the equality line than men's (dashed lines) across all facility types, with health facilities exhibiting the most pronounced inequality for both genders.

4. Discussion

4.1. Urban facility accessibility insights

Spatial accessibility analysis revealed multi-dimensional inequalities in urban service delivery, with distinct patterns across facility types. High-accessibility zones concentrate in northern and southwestern peripheries for men but appear only as small, fragmented clusters for women. In contrast, low-accessibility zones dominate the central urban core for both genders, reflecting challenges such as high population density, urban congestion, and inadequate infrastructure (Figs. 3–6). These results emphasised the spatial contrasts in urban planning and

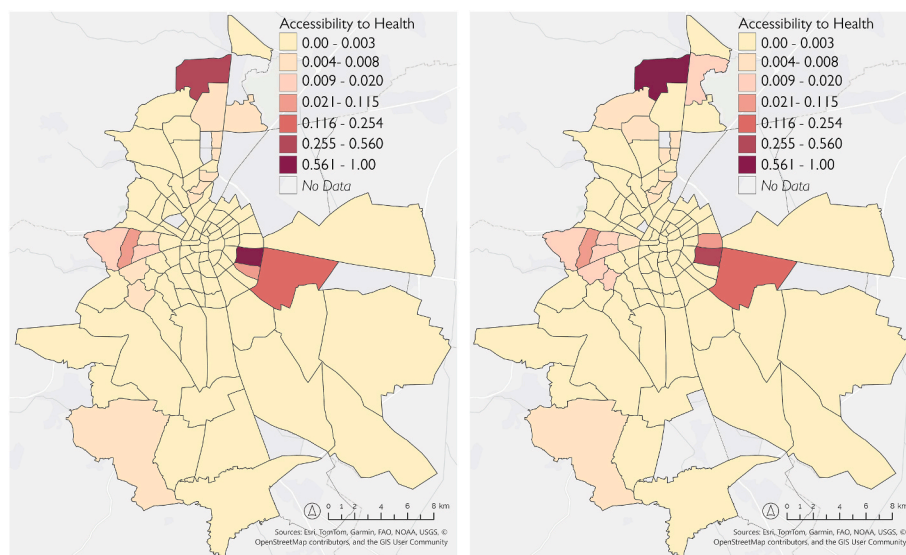


Fig. 5. Accessibility for men (left) and women (right) to health facilities.

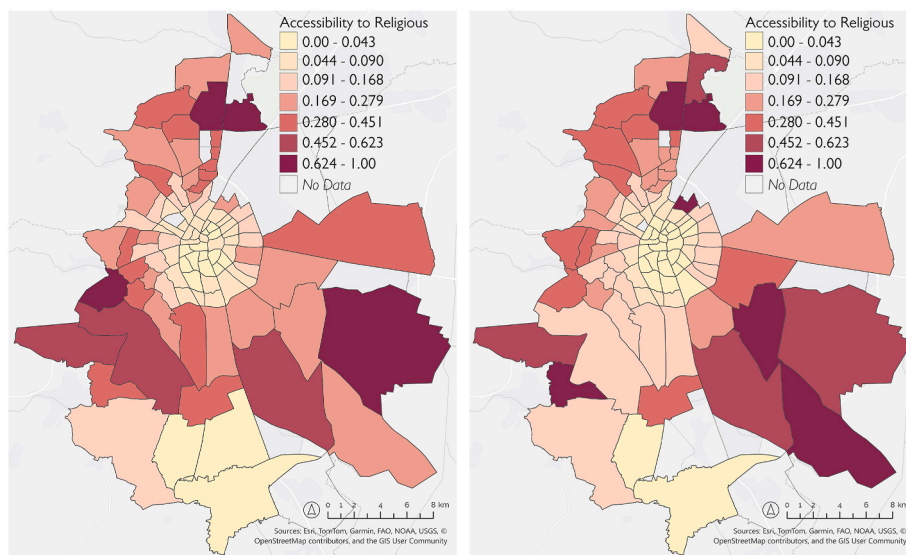


Fig. 6. Accessibility for men (left) and women (right) to religious facilities.

Table 3

Spearman rank correlations between neighbourhood-level gender distribution of refugees and facility counts.

Facility type	Male-to-female ratio			Women's proportion		
	rho	p-value	Sig.	rho	p-value	Sig.
Green areas	0.192	0.059	ns*	-0.174	0.085	ns*
Healthcare	0.021	0.838	ns	-0.001	0.989	ns
Religious facilities	0.016	0.873	ns	0.040	0.696	ns
Education	0.055	0.592	ns	-0.021	0.838	ns

ns = not significant ($p > 0.05$). * $p < 0.10$, approaching but not reaching significance. Spearman rank correlation was employed, given the non-normal distribution of facility counts and refugee population figures across neighbourhoods.

transport infrastructure requirements, echoing studies discussing the central-peripheral divide in urban accessibility (Clark & Wang, 2010; Lo et al., 2011; Tal & Handy, 2010).

Across facility types, health services exhibit the most pronounced

Table 4

Wilcoxon signed-rank test results for gender differences in accessibility scores.

Facility	W	p-value	Sig.
Religious	652	<0.001	***
Health	466	<0.001	***
Education	559	<0.001	***
Green	631	<0.001	***

*** $p < 0.001$. Wilcoxon signed-rank test, $n = 96$ neighbourhood pairs.

gender gap in mean accessibility scores, whereas religious facilities show the most equitable distribution. This pattern reflects the distinct spatial configurations of each facility type: major hospitals cluster in peripheral areas (Figs. 2 and 5), while religious, education, and green facilities distribute more centrally, revealing facility-specific spatial trade-offs that differentially affect male and female refugee populations (Allen et al., 2021).

For health facilities, high accessibility scores in peripheral areas reflect a concentration effect: major hospitals such as the City Hospital

Table 5
Gini coefficients under alternative facility-specific threshold scenarios.

Facility	Gender	−50%	−25%	Base	+25%	+50%
Education	Men	0.535	0.535	0.535	0.536	0.537
	Women	0.620	0.620	0.620	0.620	0.622
Health	Men	0.919	0.919	0.919	0.919	0.919
	Women	0.937	0.937	0.937	0.937	0.937
Religious	Men	0.503	0.503	0.503	0.503	0.503
	Women	0.526	0.526	0.524	0.526	0.526
Green	Men	0.678	0.678	0.680	0.680	0.682
	Women	0.705	0.705	0.705	0.708	0.710

Thresholds were varied by $\pm 25\%$ and $\pm 50\%$ of the base facility-specific values. The full 3SFCA pipeline was recomputed for each scenario. Gini coefficients are computed on raw accessibility scores.

in the eastern periphery and University Hospitals in the western and northern peripheries generate very high attractiveness values, yet serve populations of much lower density than the city centre. The few residents living in their immediate vicinity receive disproportionately high scores, while the majority living beyond the 30-min walking threshold receive zero. This extreme spatial polarization drives the high Gini coefficients observed, particularly for women (Table 5).

For green areas, the highest accessibility scores concentrate in newer planned districts in the northern and southwestern peripheries, which feature large community parks. The older central urban core, by contrast, is characterised by dense urban fabric where available green spaces are largely limited to small neighbourhood playgrounds whose capacity is overwhelmed by high population density. This contrast between well-provisioned outer districts and the crowded centre is directly reflected in the substantial spatial inequality women experience (Gini = 0.70), consistent with literature on proximate public spaces for vulnerable populations (Allen & Farber, 2020).

Religious facilities present a more nuanced pattern. Despite the high number of mosques in the city centre, accessibility scores are higher in peripheral areas because the very high population density in central neighbourhoods, including a large refugee concentration, means that facility capacity is divided among many users, depressing individual scores. In peripheral areas, smaller populations served by a moderate

number of mosques face no such pressure, resulting in higher accessibility values.

Distributional analyses using Lorenz curves and Gini indices expose gendered disparities in how access is spatially distributed. Women consistently face more unequal distributions, with cumulative accessibility concentrated in fewer neighbourhoods. This reinforces spatial injustices even when facilities are technically proximate. Health facilities demonstrate the highest inequality for both genders, reflecting the extreme spatial concentration of hospital infrastructure, while green areas also exhibit substantial inequality (Nesbitt et al., 2019; Rigolon, 2016). While behavioural factors such as perceived safety, caregiving roles, and time poverty (Ng & Acker, 2018) likely further constrain women's realized access, our spatial analysis reveals that spatial configuration alone creates significant inequality baselines that planning interventions must address. The strong correlation between accessibility and facility attractiveness underscores the importance of balanced urban development integrating both spatial proximity and service quality.

4.2. Spatial mechanisms of gendered accessibility disparities

The findings indicated that men have consistently higher levels of accessibility than women for all facility types (Figs. 3–6). This gender disparity arises from the spatial intersection of facility distribution and refugee settlement patterns. While male and female refugees occupy overlapping neighbourhoods (Fig. 2), female refugees outnumber males in most central areas. This demographic asymmetry, combined with the peripheral clustering of high-capacity facilities (particularly health and green areas), creates systematic spatial disadvantage. Spearman rank correlation analysis confirmed that facility distribution is spatially independent of refugee gender composition (Table 3), indicating that observed accessibility gaps arise from differential population concentration rather than gendered facility allocation patterns.

These disparities align with previous research spotlighting gender-based barriers to urban access (Golizaei et al., 2023; Kwan, 1999; Smith et al., 2022). However, our research advances the discussion by focusing on refugee populations. While literature extensively documents

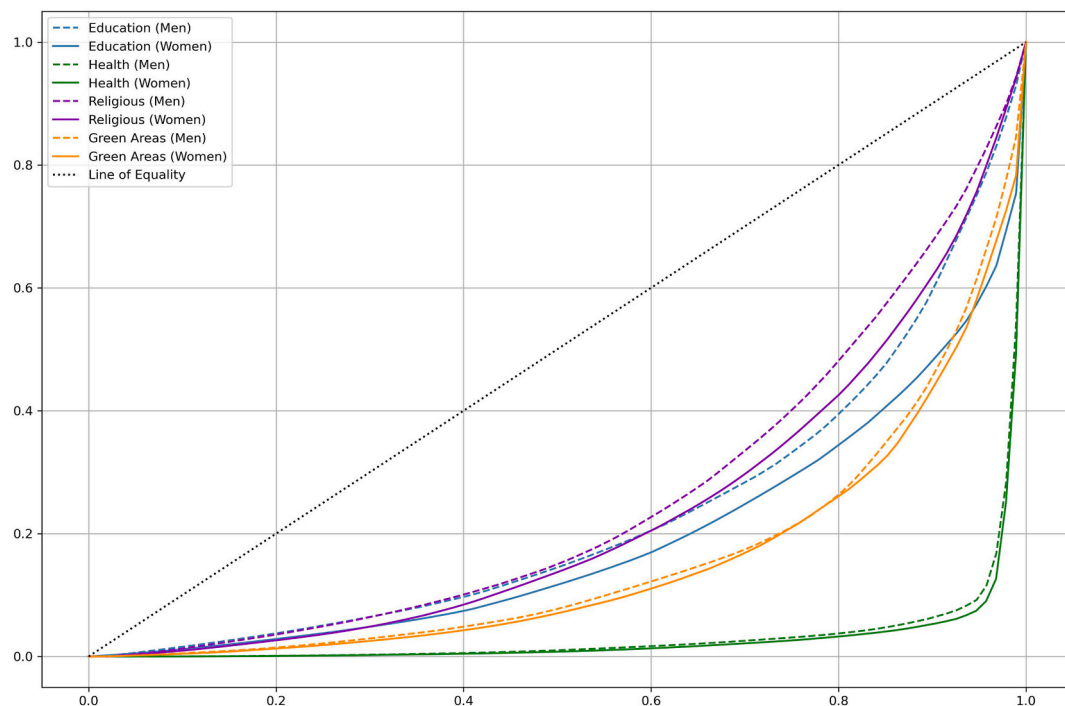


Fig. 7. Lorenz curves of accessibility to urban facilities by gender.

those behavioural and experiential factors, such as safety concerns, mobility limitations, and socio-cultural norms compound accessibility barriers for refugee women (Goliaei et al., 2023; Kwan, 1999), our spatial analysis demonstrates that service distribution alone creates significant baseline inequality, independent of these behavioural constraints. This spatial-structural foundation provides essential targets for planning interventions.

While this study employs uniform travel assumptions across genders, we acknowledge that men may hold a structural mobility advantage in practice. In many societies, and particularly among refugee populations, women's independent travel is constrained by caregiving responsibilities, perceived safety risks, and socio-cultural norms governing spatial mobility (Ravensbergen et al., 2023; Xu et al., 2020). The uniform assumption is therefore an intentional methodological choice: by holding behavioural parameters constant, the analysis isolates the spatial-structural component of inequality, establishing a conservative baseline that real-world disparities likely exceed. Syrian refugee households in Türkiye predominantly rely on walking as their primary mode of transport, given limited vehicle ownership and restricted economic resources (Ozkazanc, 2021), which amplifies the spatial inequalities documented in this study.

For Syrian refugee women in Konya specifically, mobility constraints are compounded by displacement-related vulnerabilities that evolve across the settlement trajectory. Newly arrived refugees face acute restrictions due to limited spatial familiarity, language barriers, and the absence of social networks (Farber et al., 2018; Ozkazanc, 2021). As settlement progresses, economic participation and urban familiarity may gradually expand effective mobility, yet for women, this trajectory is often slower and more constrained, as caregiving roles and socio-cultural norms persist independently of settlement duration (Cag & Ozkazanc, 2025; Enderle, 2024). In healthcare specifically, the linguistic barrier and absence of professional translation services present persistent challenges, disproportionately affecting women refugees in Türkiye (Cloeters & Osseiran, 2019; Floyd & Sakellariou, 2017).

Women's lower accessibility to green spaces (Fig. 4) reflects spatial-structural inequality, as green facilities are less numerous and more distant in neighbourhoods where refugee women concentrate. This spatial disadvantage exists as a baseline condition that behavioural and experiential factors further compound. The true accessibility gap in lived experience, therefore, likely exceeds what spatial analysis alone can capture, underscoring the need for complementary qualitative research that illuminates the experiential dimensions of refugee women's urban mobility.

Another important finding is that religious facilities exhibit the lowest level of gender inequality and the highest accessibility scores for women (Fig. 6). Literature suggests that mosques serve important social and religious functions for women (Khan & Nia, 2023). From a spatial perspective, religious facilities demonstrate favourable accessibility conditions: low threshold distances (Table 1), high facility density, and well-distributed spatial coverage make them readily accessible, particularly for women.

Health facilities present a contrasting pattern. Compared to education and green areas, gender disparities in health access are less pronounced in spatial distribution. However, health facilities show the lowest overall accessibility scores across both genders, reflecting sparse spatial distribution and geographic concentration in peripheral locations distant from central neighbourhoods where many refugees reside. The spatial distribution differs markedly from other facility types: while education and green facilities disperse throughout the study area, health services cluster in peripheral areas housing major hospitals. While experiential research documents additional barriers refugees face in accessing healthcare, including language constraints and service navigation challenges (Cloeters & Osseiran, 2019; Floyd & Sakellariou, 2017; Shahawy et al., 2022), geographic configuration itself creates baseline accessibility inequality that would persist even under ideal communication and cultural accommodation conditions.

4.3. Implications for planning equitable service provision

In this section, we discuss the planning implications of Konya's spatial accessibility patterns at two levels: context-specific interventions for the city itself, and transferable planning and policy principles for other urban contexts experiencing refugee settlement.

The central-peripheral divide documented in this study presents a fundamental planning challenge. Central neighbourhoods housing the highest refugee concentrations, particularly female refugees, exhibit the lowest accessibility across all facility types (Figs. 3–6), while high-capacity facilities cluster in peripheral areas. Addressing this structural mismatch requires spatially targeted interventions rather than generic service expansion.

For health facilities, where overall accessibility is lowest for both genders and spatial concentration in peripheral locations is most pronounced, decentralisation of primary healthcare services to central neighbourhoods is the most urgent priority. Given the persistent linguistic barriers facing refugee women in healthcare settings (Cloeters & Osseiran, 2019), low-barrier service models, such as mobile health clinics and women-only consultation spaces, represent complementary strategies that address both spatial and experiential barriers simultaneously.

For green areas, which exhibit the second highest within-group inequality for women (Gini = 0.70), interventions should prioritise the provision of accessible, safe, and culturally inclusive green spaces in central neighbourhoods where female refugee populations concentrate. The city centre's ongoing urban transformation project (195-ha designation, 2017) presents a concrete opportunity to integrate gender-sensitive green space planning into an already-committed public investment.

Religious facilities offer an instructive spatial model in Konya. Their low threshold distances, high density, and well-distributed coverage produce the most equitable accessibility outcomes across both genders in this study. Urban planners can draw on this distribution logic, short catchment distances, and fine-grained spatial coverage as a benchmark for planning other facility types, particularly green areas and primary health services, in refugee-dense central areas.

The northern, southwestern, and southeastern peripheries, which exhibit the highest current accessibility values and are designated for residential development (Özdil & Urfaloğlu, 2024), present opportunities for proactive integrated service planning. As these growth areas develop, embedding gender-sensitive accessibility standards from the outset can prevent the replication of the central-peripheral divide in emerging residential zones.

Beyond Konya, this study offers a transferable analytical and planning framework for refugee-receiving cities. The 3SFCA method, applied with gender-disaggregated population data, provides a replicable baseline measure of spatial-structural inequality that is independent of behavioural assumptions. Municipal planning departments can embed this approach into standard service equity assessments, enabling systematic monitoring of gendered accessibility gaps as refugee populations and service distributions evolve.

The Spearman correlation analysis employed in this study, testing whether facility distribution is spatially independent of refugee gender composition, offers a simple diagnostic tool for planners to distinguish between supply-side and demand-side drivers of accessibility inequality. This distinction has direct policy relevance: where gaps are demand-driven, as in Konya, interventions should target residential areas and mobility infrastructure rather than facility relocation alone.

More broadly, the finding that spatial configuration alone generates significant baseline inequality, before accounting for behavioural constraints such as caregiving burdens, safety perceptions, and linguistic barriers, underscores the importance of spatial analysis as a necessary foundation for gender-responsive urban planning. Qualitative and participatory approaches remain essential for illuminating experiential barriers, but spatial baseline measurement provides the evidence base

that planning interventions require to be targeted, justified, and evaluated.

4.4. Limitations and future research

While this research provides valuable insights, several limitations warrant acknowledgement. The reliance on static demographic and facility data does not capture temporal variations in accessibility, such as peak usage times or seasonal demand. Our refugee population data, sourced from a local NGO operating in collaboration with UNHCR, may not fully capture refugees outside institutional contact, though members are drawn from the most disadvantaged groups through systematic random sampling. Methodologically, employing uniform travel assumptions (walking mode, standardised speeds) isolates spatial-structural inequality but does not capture behavioural variations in actual mobility patterns. This approach provides a conservative baseline measure; real-world accessibility disparities likely exceed our estimates when behavioural constraints are considered. As uniform behavioural parameters are applied across genders, all observed accessibility gaps derive from the differential spatial concentration of male and female refugees across neighbourhoods, confirmed by Spearman rank correlation analysis showing facility distribution to be spatially independent of refugee gender composition. The binary gender categorisation of the data source represents a further limitation. Future research incorporating more inclusive gender identity data would better capture the full diversity of refugee populations.

Future research could address these limitations through: (1) incorporating multi-modal transportation networks and dynamic data sources (real-time traffic, temporal service availability) with advanced spatial statistical methods (Çiriş et al., 2024) and explainable machine learning algorithms (Erdem Okumus & Akay, 2025); (2) integrating qualitative insights from refugee communities, particularly women, to illuminate experiential factors compounding spatial inequalities; and (3) conducting comparative analyses across multiple cities to test generalizability and identify contextual moderators of spatial accessibility patterns.

5. Conclusion

This study quantified gender-based accessibility disparities among refugee populations in Konya, Türkiye, using the 3SFCA method. Men exhibit consistently higher accessibility across all facility types (education, health, green areas, religious facilities), while women face pronounced limitations, particularly in health and green facilities where low-accessibility zones spatially overlap with their residential concentrations. The analysis advances understanding by quantifying spatial-structural inequality beyond behavioural factors. Results demonstrate that urban service distribution creates systematic disadvantage for refugee women before accounting for additional mobility constraints, providing a conservative baseline for planning interventions. This focus on refugee populations, a demographic often overlooked in accessibility research, reveals that refugee women face compound disadvantage requiring gender-sensitive urban planning strategies.

Methodologically, the study integrates 3SFCA-derived accessibility scores with Lorenz curves and Gini coefficients, enabling simultaneous assessment of both magnitude and distributional equity of spatial access disparities. This analytical framework, while present in broader urban equity research, represents the first application to gendered refugee accessibility patterns. The findings underscore that spatial planning interventions targeting service distribution can significantly reduce baseline accessibility inequality. While this study focused on Konya, the methodological approach is transferable to other urban contexts experiencing refugee settlement. Embedding such spatial analyses into municipal planning processes can inform gender-responsive urban governance and enhance spatial equity for vulnerable populations.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used Claude to improve language and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Mert Akay: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Seçkin Çiriş:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Seher Özkazanç:** Conceptualization, Data curation, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.apgeog.2026.104121>.

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