

Geomatics-Based Assessment of Walkable Market Accessibility and Traffic Impacts in Planned Urban Areas: Implications for Sustainable Residential Planning in Delhi

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Abstract: Market distribution within planned urban settlement areas may still produce accessibility disparities and traffic imbalances. These dynamics can weaken pedestrian vitality and threaten the quality of residential spaces.

This study aims to examine how the distribution of regulated markets influences walkability-based accessibility and adjacent traffic flows in planned residential areas of Delhi. The objective is to identify spatial patterns that either sustain or degrade urban residential environments and to investigate the potential of integrated spatial analysis in risk mitigation.

Using geospatial datasets-based congestion indicators, the study applies buffer analysis, and hotspot analysis to: (i) map market distribution; (ii) assess gaps in walkable catchments; and (iii) quantify links between market accessibility and road traffic intensity.

The findings reveal significant spatial inequities in walkable access to formal markets and demonstrate that areas with insufficient market catchments show low traffic utilization, whereas highly concentrated areas correspond with traffic saturation. These insights provide a replicable, data-driven model for strategically improving walkability, mitigating congestion, and preventing residential space degradation in rapidly urbanizing regions.

Keywords: spatial equity, service catchments, pedestrian mobility, urban vitality, congestion dynamics

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1. Introduction

Poorly balanced spatial distribution of commercial markets contributes to subtle yet persistent forms of urban space degradation. Residential areas with insufficient market accessibility often experience diminished pedestrian flows, weak local commerce, and weakened neighborhood cohesion. Conversely, overconcentrated commercial clusters may generate congestion, pollution, and environmental stress, ultimately eroding livability and undermining the sustainability of planned residential settlements. Achieving a balance between accessibility and mobility is therefore fundamental for maintaining urban vitality and preventing functional decline. From the perspective of environmental sustainability, pedestrian accessibility plays a central role, as walking constitutes the least resource-intensive and least polluting mode of everyday mobility.

Markets function not only as commercial nodes but also as spatial anchors, shaping patterns of movement, social interaction, and local economic resilience [1, 2]. Their distribution directly affects walkability, transport dynamics, and spatial equity [3]. Excessive clustering may overload mobility networks and degrade environmental quality [4], while sparse provision risks underutilization and socio-economic stagnation. These dynamics are closely aligned with the United Nations 2030 Agenda for Sustainable Development, particularly SDG 11 (Sustainable Cities and Communities), which emphasizes inclusive, accessible, and environmentally responsible urban planning [5, 6] as well as SDG 13 (Climate Action) and SDG 3 (Good Health and Well-being) [7, 8].

Despite the growing recognition of these relationships, empirical evidence remains limited in the context of planned urban settlements. Existing studies rarely integrate analysis of (i) market spatial distribution, (ii) realistic walkable catchments adjusted to pedestrian infrastructure quality, and (iii) observed traffic flow intensity. Yet these dimensions jointly influence the risk of residential space degradation: insufficient market provision reduces the routine activity necessary to sustain local vitality, while excessive concentration contributes to congestion-driven environmental and infrastructural stress. The issue is especially relevant for planned settlements managed by Urban Local Bodies (ULBs), who are mandated to provide market infrastructure [9], but often struggle to ensure equitable accessibility, even where land-use regulations are formally established [10].

This study addresses these gaps by analyzing planned residential settlements developed by the Delhi Development Authority (DDA) through an integrated spatial approach combining open geospatial datasets, including OpenStreetMap (OSM), Google Street View-based pedestrian infrastructure assessment, and typical traffic-flow and real-time traffic congestion data from Google Maps. The study aims to: (i) map spatial patterns of market distribution, (ii) identify walkable accessibility gaps using a walkability-adjusted pedestrian catchment framework, (iii) examine the relationship between market accessibility and traffic conditions on adjacent road

networks, and (iv) investigate the potential of integrated spatial analysis in developing informed, risk-mitigating planning strategies.

Furthermore, the authors posit that improving pedestrian accessibility to everyday services represents a key pathway toward environmentally sustainable and SDG-consistent urban development.

1.1. Research Gaps

Although existing research clearly demonstrates the significance of service accessibility, commercial-market distribution, and mobility dynamics for the functioning of residential environments, several important gaps remain, particularly in the context of formally planned urban settlements. First, there is a notable lack of integrated analyses that jointly examine market distribution patterns, walkable catchments, and traffic flow intensity. Most studies address these elements separately, which hinders the identification of systemic mechanisms that contribute to the degradation of residential space. Second, while it is widely recognized that disparities in service distribution shape mobility behavior, empirical evidence linking variations in market accessibility to transport system performance and neighborhood vitality is still limited, especially within pre-planned urban layouts. Third, despite the increasing availability and reliability of open geospatial datasets such as OpenStreetMap and Google Maps, their potential for analyzing commercial-service accessibility and its mobility implications remains underutilized. Finally, the literature reveals a shortage of studies focusing on planned settlements in the global south, particularly those developed by agencies such as the Delhi Development Authority, where rapid urbanization amplifies the risks associated with accessibility imbalance and environmental degradation.

1.2. Contribution of the Study

This study seeks to address the above gaps by providing both methodological and empirical advancements. It develops an integrated analytical framework that links market distribution, walkable accessibility, and traffic impacts through the use of open geospatial data sources. Empirically, the research offers novel insights into large-scale, formally planned residential areas developed by the DDA in Delhi, where notable accessibility disparities persist despite structured land-use planning. The findings demonstrate how imbalanced market provision, whether through under- or over-supply, relates to variations in traffic intensity and contributes to the progressive degradation of residential environments. In addition, the study formulates practical planning guidelines for sustainable market provision that align with SDG 11.3 and promote more balanced, equitable accessibility within planned settlements. By foregrounding walkability as a core analytical and planning variable, the study directly contributes to sustainability-oriented urban research aligned with the SDG 2030 agenda.

1.3. Research Questions

In response to the identified gaps and objectives, the study addresses the following research questions. First, what are the spatial distribution patterns of regulated markets within residential settlements planned by the DDA? Second, what is the impact of the distribution of regulated markets on walkable accessibility? Third, how does the existence of these markets influence the residential environment across the study area? Finally, what is the potential of integrated spatial analysis to inform planning strategies aimed at mitigating the risks of residential space degradation and enhancing the long-term sustainability of urban environments?

2. Literature Review

The literature review has been organized into the following thematic sections: Theoretical Foundations of Urban Structure and Service Nodes, Evolution of GIS-Based Accessibility Metrics, Data Reliability and Open Geospatial Portals, Impact of Markets on Urban Mobility and Vitality, Global South Context and Sustainability Goals, and Walkability. This structure was adopted to facilitate a clearer understanding of the individual research themes and to present the theoretical background in a more logical and coherent manner. The thematic division allows readers to more easily follow the evolution of concepts, methods, and research findings relevant to the study.

2.1. Theoretical Foundations of Urban Structure and Service Nodes

Classical urban development models provide the foundational framework for understanding how market nodes and service ranges organize urban space. Frameworks such as von Thünen's land-use model [11] and central place theory [12] highlight the critical relationship between distance-based service ranges and spatial organization. These concepts were further expanded through Burgess' concentric zone model [13] and Hoyt's sector theory [14], which position commercial hubs as primary drivers of urban morphology. Modern planning paradigms, such as New Urbanism, have shifted the focus toward mixed-use design and walkable service access to foster social equity and neighborhood vitality [15, 16].

2.2. Evolution of GIS-Based Accessibility Metrics

The concept of accessibility was first formally introduced by Walter G. Hansen in 1959 [17]. In Hansen's original formulation, accessibility refers to the ease with which activities (such as jobs, services, or social interactions) can be reached from a given location, considering both the spatial distribution of opportunities and the cost of reaching them (e.g., distance or travel time). Spatial accessibility has evolved from simple distance measurements into a multidimensional construct integrating

land-use and transportation performance [4, 18]. Modern research frequently employs sophisticated tools like the two-step floating catchment area (2SFCA) method to quantify service access and identify inherent spatial inequities [19]. Furthermore, the integration of kernel density estimation (KDE) and hotspot analysis makes it possible to visualize commercial clusters and identify underserved regions within complex urban fabrics [20, 21].

2.3. Data Reliability and Open Geospatial Portals

The reliability of open-source geospatial data, such as OpenStreetMap (OSM), has become a cornerstone for replicable urban research [22]. While data completeness can vary, recent validation studies confirm that OSM is a robust tool for assessing food-related points of interest and street-network attractiveness [23]. Additionally, tools like Google Street View provide high-resolution photographic evidence that allows for micro-scale assessments of pedestrian infrastructure quality, such as footpath adequacy and aesthetic comfort.

2.4. Impact of Markets on Urban Mobility and Vitality

Markets serve as “spatial anchors” that fundamentally structure pedestrian flows and support local economic resilience [24]. A balanced provision of these nodes is essential; over-concentration can lead to transport network saturation and environmental stress, while sparse provision risks socio-economic stagnation [25]. Empirical evidence suggests that commercial concentrations significantly impact adjacent road networks, with traffic intensity often peaking during evening hours when local commercial activity is highest [26, 27].

2.5. Global South Context and Sustainability Goals

While much literature focuses on Western models, there is a critical need for research on planned settlements in the Global South, where agencies like the Delhi Development Authority (DDA) manage rapid urbanization [3, 4]. Improving walkable access to local services is recognized as a primary strategy for achieving the United Nations Sustainable Development Goals, particularly SDG 11 (Sustainable Cities and Communities), SDG 3 (Good Health and Well-being), and SDG 13 (Climate Action).

2.6. Walkability

Walkability can be defined as the degree to which an urban environment accommodates the diverse needs of pedestrians [28]. Walkability studies across multiple regions adopt a relatively consistent reference distance, commonly around 400–450 m, reflecting a comfortable 5–10-minute walking trip [29–37]. These distances have also informed planning benchmarks and GIS-based analyses of neighborhood environments.

A detailed walkability assessment conducted for Dwarka [38] employed a structured methodology with three categories: Footpath Adequacy, Footpath Quality, and Comfort/Aesthetics/Security, divided into 12 sub-indicators (width, continuity, condition, obstructions, amenities, lighting, etc.). Scores from 1 (worst) to 5 (highly walkable) provide a quantifiable measure of pedestrian infrastructure quality. While walkability metrics are well established, their integration with market accessibility and real-world mobility patterns, particularly traffic flow data, remains rare, limiting the ability to evaluate how pedestrian conditions interact with commercial distribution in shaping urban vitality.

3. Methods and Materials

This section provides a detailed explanation of the methodological approach adopted in the study, including the research framework, data sources, analytical procedures, and tools used. A graphical diagram (Fig. 1) illustrates the workflow from data acquisition to the interpretation of the results.

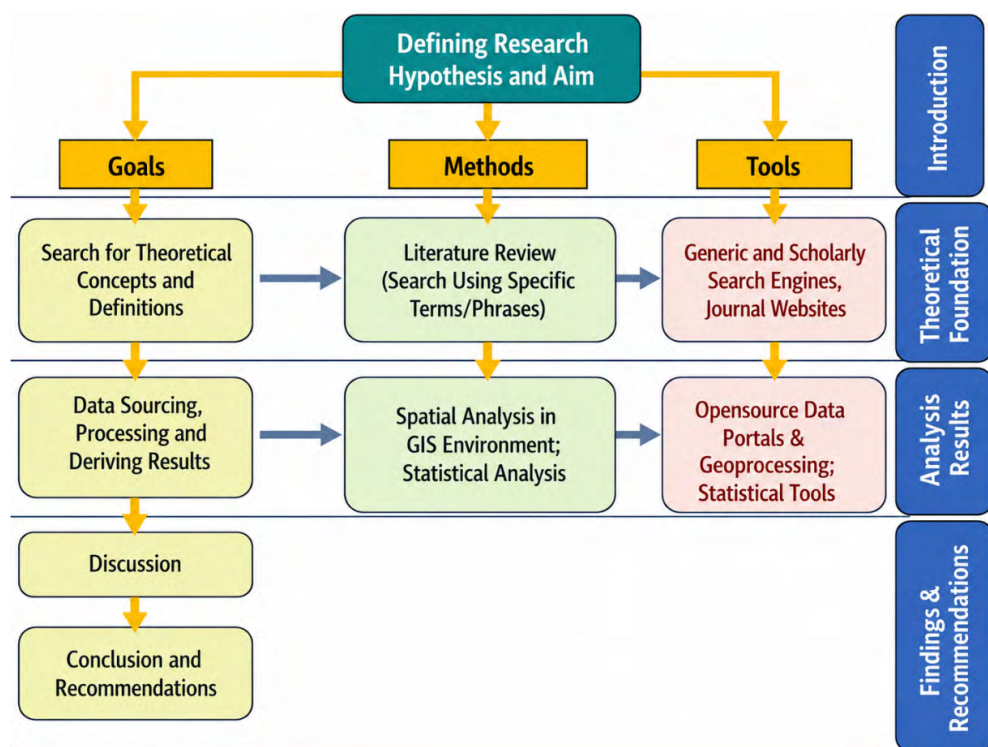


Fig. 1. Generic research framework representing major stages of the study

3.1. Research Framework

After defining the research hypothesis and aim, the methodological strategy (Fig. 1) was developed to integrate theoretical inquiry with spatial analysis.

The first stage consisted of an extensive literature review aimed at identifying conceptual foundations relevant to the study. The search included theoretical models related to planning and development of urban settlements, accessibility, spatial accessibility, walkable distance in neighborhoods, walkability, and spatial tools for buffering and clustering analysis. The following academic sources and indexing services were utilized: generic Google search, Google Scholar, journal publishers such as ScienceDirect, Elsevier, and Taylor & Francis, as well as EBSCOhost, and Web of Science (WoS).

To ensure transparency and reproducibility, a set of inclusion criteria was adopted: (i) publications from 2000–2024 addressing accessibility or walkability; (ii) studies employing GIS-based spatial analysis; and (iii) research focusing on planned urban settlements in rapidly growing metropolitan areas. Exclusion criteria included non-peer-reviewed documents and studies without methodological clarity.

The analytical phase is crucial to obtaining answers to the questions of spatial distribution patterns of the markets, walkable accessibility, influence on the residential environment, and exploring the potential of integrated spatial analysis toward informing mitigation strategies. This phase involved generating, processing, and interpreting spatial data using a GIS environment. Geoprocessing tools such as digitization, buffering, proximity analysis, and hotspot analysis were used to assess spatial patterns of accessibility. Satellite imagery was obtained from open-source platforms, including Google Earth and OpenStreetMap. These were used for determining the study area boundary and identifying 19 formal market locations, which were digitized manually in the QGIS software as vector GIS datafiles. Google Street View was used to determine the location and other characteristics of the markets for inclusion. Inclusion criteria required the combination of location, shape, size, façade of visible clustering of retail units, and accessibility from public roads, which together provided the spatial distribution pattern of the markets. The study area was divided into 500 m² grid units, which is a little more than the global walking accessibility average of 400–450 m described in the literature review section (Chapter 2). It provides a standardized spatial framework for measuring the distance from residential blocks to the nearest market node. Hotspot analysis, typically based on kernel density estimation (KDE), visualizes the clustering intensity and identifies spatial concentrations within point datasets [39, 40]. The KDE-derived maps facilitate the detection of commercial, mobility, and activity hotspots, enabling rapid interpretation of spatial patterns that are relevant to accessibility and urban design. In this study, rather than a simple count, the KDE analysis identified the intensity of the concentration of markets. The raster values represent relative clustering intensity, identifying “hotspots” where the supply of commercial nodes is highest per unit area.

While the standard literature often cites 400–450 m as a walkable threshold, the study intentionally reduced this to 300 m to reflect the specific ground realities of Dwarka. As documented in external audits [38], the pedestrian infrastructure in Dwarka, despite being “planned,” suffers from significant issues: footpaths are often too high, lack universal accessibility features (ramps/tactile pavers), and are frequently obstructed by vendors, parked vehicles, or poor maintenance. This “below-average” infrastructure rating necessitated a more conservative catchment to accurately model realistic pedestrian accessibility.

Photographic material was sourced from Google Street View to provide a visual validation for the determined walkable accessibility in Dwarka around the market areas. This observation of real-world constraints, such as footpath height, vendor encroachments, and lack of crossings, justified the reduction of the standard 400 m walking radius to a more realistic 300 m threshold for this specific context. This “buffering process” (using the Buffer tool in QGIS) enabled a quantitative assessment of “spatial equity,” identifying exactly what proportion of the planned sectors lacks immediate access to formal markets.

When determining market catchment areas in Dwarka, the Buffer tool in QGIS helped to visualize separate circular distance thresholds. The circular buffers were employed because current open-source network data (from OSM) for this specific region lacks the high-resolution pedestrian attribution (such as mid-block crossings, pavement quality, missing footpaths and localized barriers) required for accurate network-based modeling. Given these data limitations, circular buffers provide a consistent and replicable approximation of accessibility when combined with walkability-adjusted distance thresholds, which avoids the false precision of a network analysis based on incomplete infrastructure data.

To assist in understanding the potential influence of the existence of regulated markets on the residential environment in terms of traffic movement, hourly traffic-flow data at 8 pm were collected for both weekends and weekdays under the “Typical Flow” category in Google Maps for each relevant road segment [41]. The data were collected from the Google Maps website in July 2025. The category of “Typical Flow” of the traffic is considered by the authors to represent a common or regular pattern of the average traffic flow for that hour. There is no information available on seasonal variations or any unexpected events. Similarly, the specific time window of 8 pm was chosen to isolate and reflect the traffic due to neighborhood-level market activity. At 8 pm, confounding variables such as school-related transit and peak office-to-home commuting have largely subsided, while local commercial activity remains at its peak. This provides a clearer correlation between market presence and observed traffic patterns on adjacent roads.

The traffic data were manually compiled in Microsoft Excel, converted into ordinal code values, and subsequently transformed into GIS-compatible formats (.csv/.shp) for spatial visualization. Google Maps displays the traffic in color codes in green, yellow and two shades of red. Green represents clear traffic, seeing the highest speed.

Yellow represents an intermediate speed, lower than green. Red and dark red subsequently represent even lower speeds than yellow. Traffic combinations were observed for various road segments in the area. The speeds often vary on the same road segment, which is captured by the Google data in these colors. The combinations varied in different directional flows as well as in the same directional flow from one end to another, or near a crossing of the same road segment. These combinations are categorized manually in 13 separate stages of traffic flow (see Table 1), which are largely representative of what was observed at a particular place at a specific time period. Traffic data is provided by Google for each hour. The traffic speed ranking codes, ranging from 1 to 13, represent the average traffic flow category for individual road segments. These values are derived from real-time traffic feeds aggregated for the observed hour across multiple days of the week. A traffic speed ranking code of 1 indicates the heaviest traffic flow, while a traffic speed ranking code of 13 represents the lightest traffic flow for the corresponding hour and day. The codes in between, such as 2, 3 through 11, 12, represent the traffic flow in between.

Table 1. Ranking codes of traffic flow

Traffic Flow	Rank Code
Green	13
Only crossing partial yellow	12
Only crossing partial yellow red	11
Marginal yellow	10
Marginal yellow red	9
Partial yellow	8
Partial yellow red	7
Partial red	6
Dominant yellow	5
Partial red yellow	4
Dominant yellow red	3
Dominant red yellow	2
Dominant red	1

- A two-step verification process was applied to enhance the data quality:
1. cross-checking digitized features with multiple imagery sources;
 2. validating traffic-flow intensity by comparing three different days of the week to reduce stochastic anomalies.

The results of these analyses are interpreted in the discussion section (Chapter 5), where limitations of the study, the valuable insights it provides into the implementation gaps, and the potential planning interventions are also included. The study concludes with recommendations grounded in both empirical findings and theoretical considerations. Short profiles of Delhi and the case study area are also included to contextualize the topographical, demographic, and land-use characteristics.

3.2. Study Area

Delhi, the capital city of India and a major global megacity, was selected for this study due to its rapid growth and diversity of planned and unplanned settlements. The city has seen rapid growth both horizontally and vertically in the past few decades. Numerous planned and unplanned settlements have been developed over this period in different parts of the city. The Dwarka area was chosen as the case study because it is one of the most systematically planned sub-cities developed in the post-millennium period (Fig. 2). It hosts a substantial residential population and includes a well-distributed network of planned markets.

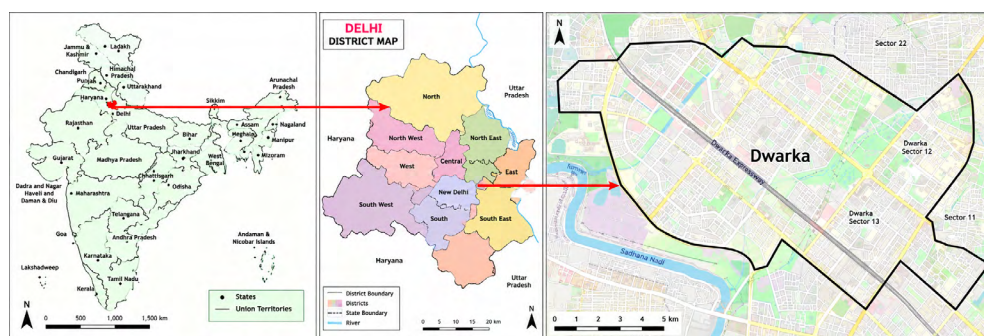


Fig. 2. Map of Delhi and study area

Source: own elaboration based on [42] and [43]

3.3. Delhi: The Capital City of India

After independence, new areas in Delhi were developed primarily for immigrants from Pakistan and later for central government employees arriving from other parts of India. With growing urbanization pressures, the Delhi Development Authority (DDA) was established in the late 1950s to guide urban development. Over the decades, the DDA created multiple planned residential and commercial zones. However, with the burgeoning population and demand for planned residential areas, the DDA also planned for urban extension areas within the city limits. Therefore, there are presently numerous settlements developed in different eras. In its Master Plans for Delhi land use, each serving for twenty years, the DDA planned and then developed these settlements as per the accepted rules and regulations of those eras [44].

Delhi today is a metropolitan city composed of eleven districts covering an area of 1,485 km² [45]. Each district includes markets, administrative zones, and diverse residential areas. Planned and unauthorized settlements coexist in the urban fabric, with mixed land-use patterns contributing to local-scale commercial development. The city provides shelter, livelihood, and social life to a large population.

3.4. Case Study Area: Dwarka

The Dwarka sub-city covers 5,648 ha, of which 1,688 ha are designated as built-up area, while the remaining 3,960 ha encompass regulated development across sectors 1–29. According to the Master Plan for 2001 for Delhi prepared by DDA, an estimated population of more than 1.1 million was to be accommodated in the Dwarka sub-city (Zone K-part). As per MPD-2021, the holding capacity of Zone K-II has been proposed for a population of 1.3 million. The size of the zone was increased to 5,924 ha by adding the land between Bijwasan Road and the boundary of the National Capital Territory of Delhi [46]. A wholesale market is also planned for the area within the framework of MPD-2021 [47].

Dwarka represents an exemplary environment for studying accessibility in structured, post-millennial urban development due to its grid-based planning, hierarchical road network, and functional zoning. These characteristics make it suitable for spatial analysis involving digitization, buffering, and pattern detection.

4. Results

4.1. Walkable Accessibility in Dwarka and Spatial Distribution of Markets

Two types of development can be identified in Dwarka: planned and unplanned. This study focuses only on the part of Dwarka that has been planned, while unauthorized parts are not taken into account. The planned and unplanned parts differ in terms of area covered, number and type of houses, infrastructural density, and completely different internal layout. Figure 3 shows a glimpse of the differences between the planned and unplanned parts.



Fig. 3. Planned housing apartments (a); unauthorized housing (b)

Source: [48]

4.2. Walkable Accessibility in Dwarka

Regarding the walkability in the case study area, the report prepared by the Transport Planning Department, School for Planning and Architecture, Delhi and commissioned by the Delhi Development Authority [38] clearly states that despite the presence of dedicated footpaths across almost entire sectors of Dwarka, they are unsuitable for walking (Fig. 4).



Fig. 4. Lack of maintenance near Ayudhvihar Chowk (a); footpath too high and no marked pedestrian crossing near Sector 3, Aastha Kunj (b); lack of cleanliness, vendor encroachment on footpath near Aashirwad Chowk Market and access to footpath partially blocked (c)

Source: [48]

According to the DDA report [49], the following major issues were identified:

- Footpath height is too high in a lot of areas, thus discouraging pedestrians.
- Footpaths are not designed for universal accessibility, and ramps and tactile pavers are missing across all sectors.
- A lack of maintenance resulted in broken footpath surfaces, broken drain covers, and unclean footpaths in many areas.
- Encroachment by hawkers and vendors or obstructions such as transformers and trees block the paths.
- Parking encroachment occurs on footpaths in high-intensity commercial areas or near schools.
- On-street parking is a more significant problem in the K-II village area compared to the Dwarka sub-city.
- Sectors lack adequate lighting for footpaths in the majority of sectors, despite having streetlights.
- Limited pedestrian crossing facilities leave pedestrians extremely vulnerable to being involved in traffic accidents
- Pedestrian crossings are improperly marked or absent at many intersections and/or are entirely on both sides of the street.

A street cross-section inventory, along with a supplementary walkability audit, was undertaken to evaluate the overall walkability conditions across the sectors. The assessment covered all primary street networks and a representative sample of secondary networks throughout Dwarka.

The methodology used to compute the walkability index for Dwarka is based on the previously outlined concept of walkability and incorporates indicators grouped under three broad categories:

- 1) footpath adequacy;
- 2) footpath quality;
- 3) comfort, aesthetics, and security.

These indicators were further broken down into 12 sub-indicators. The methodology assigns equal weight to each of the sub-indicators such that it can be expressed as:

$$\text{walkability index} = \text{average of scores of indicators 1–12.}$$

The minimum score, and therefore the minimum that a link or sector can achieve, is 1, while the maximum is 5. The scores obtained from the sub-indicators give a combined score between 1 and 5, where: 1 – not fit at all (worst), 2 – poor condition, 3 – average, 4 – suitable for walking, 5 – highly walkable. A walkability score is calculated for each link on the network assessed and for each sector individually for comparison.

4.3. Spatial Distribution of Markets in Dwarka

Small and large shopping markets were marked as points in the study area (see Fig. 5). The term ‘markets’ not only included semi-open structured commercial centers but also the malls in the area since they also provide similar opportunities of shopping for various types of retail items. Only difference of malls with semi-open structured markets is their security guarded entries to the buildings with closed-doors.

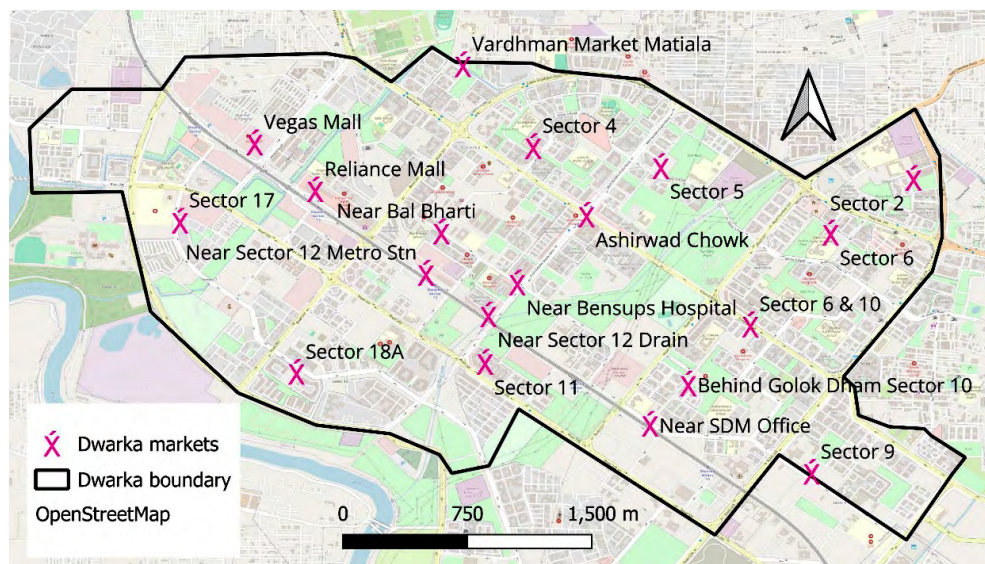


Fig. 5. Spatial distribution of market points in Dwarka (approximate boundary)

Figure 5 shows that markets across Dwarka are fairly well spread out, although there is a lack of planned markets in some areas near the demarcated boundary. Taking into account the preferred walking distance of 300 m, buffers of 100, 200 and 300 m were next created, using the markets as central points (see Fig. 6).

The difference between the buffer rings of each point reflects the lack of spatial accessibility based on walking distance for users living in certain parts of the Dwarka area. The overlap of the inner buffers at 100 and 200 m in many places reflects the greater proximity of multiple markets for users living within this distance.

A hotspot analysis was also conducted in a Geographic Information System (GIS) environment called ‘Quantum GIS’ (see Fig. 7). The raster values in the hotspot analysis represent kernel density estimates, where higher values indicate greater concentrations of market locations within a specified search radius. These values are relative and used to identify the spatial clustering intensity rather than absolute quantities.

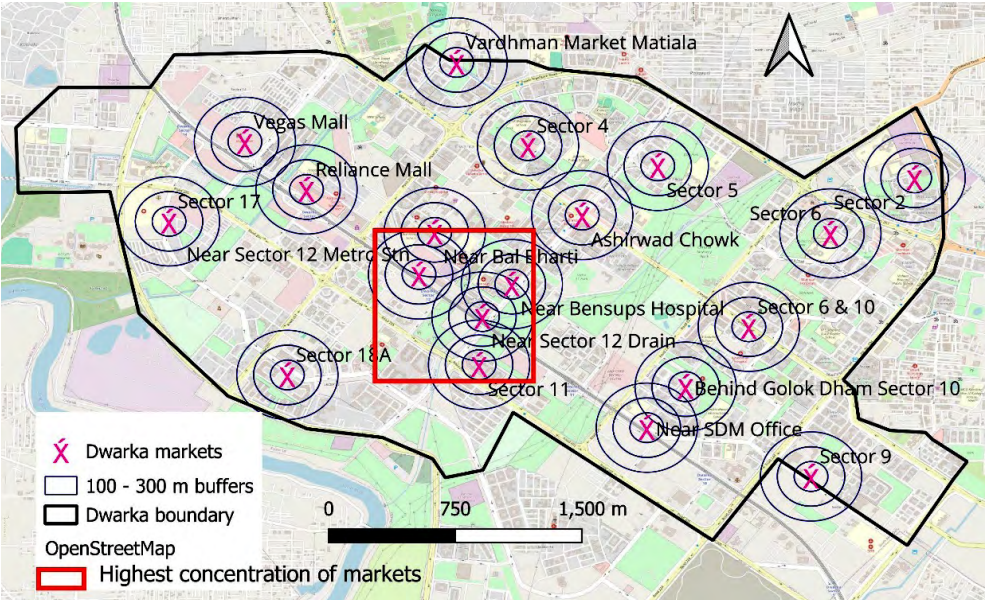


Fig. 6. Multiple buffering (100–300 m) around markets in Dwarka

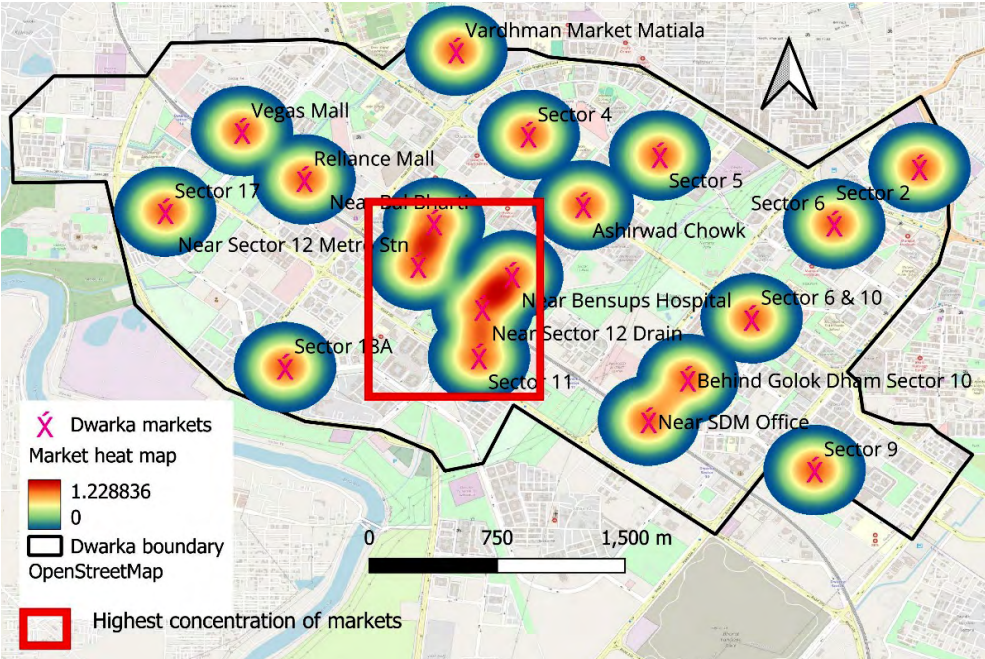


Fig. 7. Hotspot analysis of markets in Dwarka

The hotspot analysis reveals the highest concentration of market points near the central area between sector twelve metro station, Bal Bharti school, Bensups hospital and sector eleven (area approximately marked with a red square). Users living in this area enjoy greater proximity to multiple markets. Apart from the short distance from the Ashirwad Chowk market buffer, when all buffer zones in this area are added together, it becomes the main market hotspot in Dwarka.

The spatial distribution of markets in Dwarka is generally well developed; however, several peripheral and interstitial areas remain outside all designated buffer zones. These uncovered zones are predominantly occupied by institutional complexes, administrative facilities, large hotels, or undeveloped plots not intended for residential use. Nonetheless, certain residential neighborhoods in the northeastern section, in the vicinity of Sector 17, as well as substantial areas along the south-eastern boundary and western boundary, also fall outside the walkable accessibility buffers identified in the analysis (see Fig. 8).

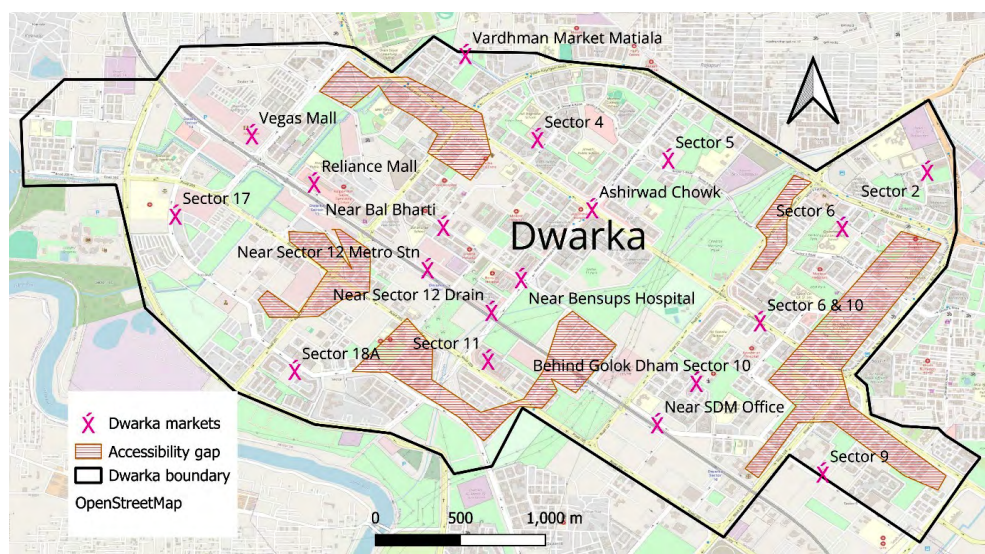


Fig. 8. Spatial accessibility gaps for local users among the 300 m buffers around Dwarka markets

It is also interesting to note that Dwarka has isolated neighborhood shops (see Fig. 9) but they provide mostly confectionery items, fruits and vegetables or some basic services like a tailor.

Despite the sparse distribution, these shops are spread across the group housing society areas, where one or two shops have been opened inside the premises of a group housing society with a window for selling items to customers outside. The highly localized targeted customer area, combined with easy walkable accessibility, is a positive point for these shops.



Fig. 9. Single neighbourhood shop in Dwarka sector 3

Source: [48]

4.4. Impact of Market Presence on Traffic Flow of Nearby Roads

Typical traffic flow, provided by Google, was observed on selected road sections in the study area at 8 pm. The traffic speed ranking codes, on a scale of 1 to 13, represent the average traffic flow category data for individual road segments, which is derived from real-time traffic feeds for the observed hour across multiple days of the week. Code 1 represents the heaviest traffic flow, while code 13 represents the lightest traffic flow category at the observed hour and day. Detailed traffic speed ranking code information is provided in the methodology section. Only the codes observed for the investigated hour at the location are represented in the legend of each map.

The typical traffic-based observations for each mentioned day are recorded on 10 May, 2025 and presented in Figure 10. Figure 10a shows observations made at 8 pm on Wednesday, Figure 10b shows observations made on Saturday, and Figure 10c shows observations made on Sunday.

The codes shown on the map correspond to those presented in Table 1. Traffic speed ranking codes (1–13) represent average traffic flow categories, with code 1 indicating the highest traffic intensity and code 13 the lowest.

It was found that on Wednesday (Fig. 10a), which is a normal working day, traffic is slower (traffic speed ranking codes 3, 5 and 8) near areas with a high density of markets compared to better traffic flow in other market areas with relatively less spatial accessibility to markets. Similarly, on Saturday (Fig. 10b) at the same time, traffic is generally relatively slower (traffic speed ranking codes 2, 3, and 5) near areas with a high density of markets. On Sundays (Fig. 10c), the typical traffic is again relatively slower (traffic speed ranking codes 2, 3, and 5) near areas with a high market density.



Fig. 10. Typical traffic flow at different locations at 8 pm:

a) Wednesday; b) Saturday; c) Sunday

The legend presents only the codes that occur on the map; if a given code does not occur on the map, it is not included in the legend

5. Discussion

The analysis demonstrates that formal planning and implementation do not ensure a uniform spatial distribution of services. While the planned residential sectors of Dwarka generally fall within walkable catchments, the existence of underserved residential areas highlights a significant disconnect between top-down land-use allocation and actual spatial equity. Consequently, residents in underserved zones may be forced into vehicle-dependent trips even for basic needs, undermining the core sustainability goals of the “neighborhood unit” concept. The observed variation in average walking distances highlights how the degradation of pedestrian environments (e.g., high footpaths, lack of maintenance, and encroachments) effectively shrinks the functional service area of planned markets. It indicates that planning objectives for uniform service provision have not been fully achieved, even in a structured, grid-based sub-city. This underscores the need for “walkability-adjusted” planning that accounts for micro-scale pedestrian barriers rather than just macro-scale land-use zoning.

The spatial patterns identified in this study both align with and diverge from established retail accessibility research. Similar to the findings of Han et. al. [21] and Islam [50], this study identifies significant commercial clustering, yet it utilizes a grid-based framework and user-defined circular search radius that offers a more realistic representation of walkability for residents not directly on the primary road network. While Kelobonye [51] examined accessibility through competitive economic demand, this study prioritizes physical ease of access as a prerequisite for urban vitality. Furthermore, the observation that market concentration directly correlates with traffic saturation during peak evening hours (especially weekends) reinforces the conclusions of Tanyi [26], Agyapong [27], and Osoja [52], who established that commercial anchors function as primary drivers of localized congestion. Tanyi [26] employed a chi-square statistical approach to analyze categorical variables and demonstrate the congestion effects of commercial activity. Osoja [52] applied regression-based statistical methods and arrived at similar conclusions. Agyapong likewise used quantitative analytical tools supported by statistical software.

By using “typical average traffic” data from Google Maps, this study provides a cost-effective, replicable method for validating these congestion effects in the Global South, where high-resolution traffic sensor data may be unavailable. The results support the study’s hypothesis that despite the formal planning of residential settlements by the DDA, the spatial distribution of regulated markets remains uneven, leading to significant walkable accessibility gaps that vary across the study area.

This study has several limitations, particularly the absence of primary data regarding the characteristics of the markets, such as the range of services and products offered, and, importantly, a lack of information on user behavior or preferences. Data on shopping frequency, variations in behavior by age or income, and factors such as vehicle ownership and driving skills were not available. Other limitations also exist, such as potential positional inaccuracies in OpenStreetMap data, and

Google Street View imagery not always being temporally consistent with real-time or average conditions. The traffic data from Google Maps serves as an aggregated estimate rather than a direct sensor measurement; the conversion into ordinal categories (ranks 1–13) acknowledges this qualitative nature with a degree of subjectivity while allowing for spatial comparison.

Nevertheless, supplementary insight can be drawn from a dataset derived from daily traffic feeds, accessible as “typical average traffic” on an hourly basis in Google Maps. The observed traffic slowdowns near market hotspots on weekends suggest that these areas have reached their carrying capacity for current mobility infrastructure. Dwarka’s high-population holding capacity of 1.1 million people contributes to this situation. This creates a paradox of urban vitality: while high activity indicates a thriving local economy, the resulting environmental and infrastructural stress, manifested as congestion and a lack of pedestrian safety, threatens the long-term livability of adjacent residential zones. Conversely, the relative traffic scarcity in areas underserved by the mapped markets, again in the context of the 1.1 million population, suggests their unequal spatial reach, which can lead to social stagnation and the functional decline of those residential spaces.

Dwarka, which has a broadly rectangular urban form, allocates substantial space for residential development in all directions, along with designated market areas. Residents living outside the outer buffer zones of market catchment areas, yet not directly next to the settlement boundaries, still have access to multiple markets nearby. Nevertheless, the findings raise important questions: How can existing clustering be reduced, and how can gaps between market catchments be addressed? Moreover, what strategies could lessen the traffic impacts observed on adjacent roads? Addressing these issues requires long-term urban planning interventions in Delhi that recognize such patterns and develop feasible, sustainable solutions.

Despite its limitations, this study offers valuable insights into gaps for the Delhi Development Authority (DDA) as it introduces new housing schemes [53]. To mitigate the risks of residential space degradation, planning interventions should move beyond traditional zoning toward dynamic accessibility management:

- Addressing accessibility gaps: Future strategies should prioritize closing service gaps in the identified underserved zones, particularly in the northeastern and peripheral sectors.
- Decentralizing service provision: Instead of allowing further intensification in identified hotspots, planners should focus on upgrading isolated neighborhood shops and “window-service” units already existing within group housing society areas. These micro-nodes provide essential services with minimal traffic impact.
- Integrating informal and village markets: Strategically integrating markets from nearby unauthorized settlements or urban villages through improved pedestrian infrastructure could bridge accessibility gaps without the need for large-scale new construction.

- Improving pedestrian-centric infrastructure: Since poor walkability scores (e.g., lack of ramps, broken surfaces) directly limit market accessibility, the rectification of physical barriers (SDG 11.7) should be prioritized over road widening or additional parking.
- Implementing context-sensitive traffic management: Applying pedestrian-priority zones and traffic-calming measures in market hotspots is essential to preserve the “good health and well-being” (SDG 3) of residents from the noise and pollution of idling vehicles.

Any future redevelopment strategy for this area should consider these elements.

6. Conclusion and Recommendations

The following conclusions have been drawn:

- The spatial analysis reveals clear differences in the distribution and spatial reach of markets across the study area.
- Several markets show limited spatial accessibility for local residents when evaluated in terms of walkable distances.
- Certain pockets exhibit clustering patterns of markets.
- Sufficient photographic evidence of walkability conditions has been provided, demonstrating the usefulness of high-resolution, globally available open-source spatial data such as Google Street View.
- Traffic on nearby roads is affected by the presence and activity of the nearby markets.
- The study’s hypothesis is supported by the evidence and validation presented.
- Due to the overall urban form of the sub-city, users often have additional market options available with only a small increase in walking distance.
- Enhancing walkable access to local markets directly supports several Sustainable Development Goals of the 2030 Agenda.

Based on the findings, it is recommended that future planning interventions in Dwarka and comparable planned settlements adopt walkability-based accessibility criteria as a core component of neighborhood service provision. Strategically upgrading isolated neighborhood shops, selectively integrating markets within urban villages and adjacent unauthorized areas, and improving pedestrian infrastructure in identified accessibility gaps could significantly enhance service coverage without intensifying existing clusters. In market hotspot areas, design based on pedestrian priority, improved crossings, and context-sensitive traffic-calming measures should be prioritized to mitigate environmental and mobility impacts.

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Authors' Contribution

T.G.: conceptualization, methodology, validation, formal analysis, investigation, resources, data curation, writing – original draft preparation, editing, visualization.

A.K.: conceptualization, methodology, validation review, writing – original draft preparation, editing, supervision.

A.D.: conceptualization, methodology, validation, review, writing – original draft preparation, supervision.

Declaration of Competing Interests

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.

Data Availability

All data are publicly available on the cited websites.

Use of Generative AI and AI-Assisted Technologies

No generative AI or AI-assisted technologies were employed in the preparation of this manuscript.

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