Ibrahim *et al. Urban Informatics* (2025) 4:19
https://doi.org/10.1007/s44212-025-00088-6

Urban Informatics

RESEARCH Open Access

Unequal green: a mixed-methods spatial assessment of urban green space provision, quality, and accessibility in Mardan, Pakistan

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Abstract

Sustainable urban development heavily relies on the provision of accessible and well-managed green spaces, which enhance environmental quality and urban livability. However, in many fast-growing cities, green spaces are unequally distributed and poorly accessible. Therefore, this study assesses the provision, spatial distribution, accessibility, quality and management of green spaces in Mardan, Pakistan, a rapidly urbanising secondary city in South Asia. Using a mixed-method approach combines GIS-based spatial analysis and field surveys to evaluate the quantity, quality, and accessibility of urban green spaces (UGS). Landsat 8/9 imagery in ArcGIS Pro 3.0 was used to evaluate the UGS coverage; accessibility was evaluated through the Two-Step Floating Catchment Area (2SFCA); and quality was assessed using a locally adapted Qualitative Green Space Index (QGSI). Results show that only 307 acres (0.87%) of land is dedicated to green space within an overall urban area of 35,126 acres, translating to a per capita availability of merely 3.1 m^2, significantly less than the recommended global benchmark. QGSI scores demonstrated considerable discrepancies, with higher education institutions excelling in management and aesthetics compared to municipal authorities. Results from the 2SFCA underscore substantial spatial inequalities in accessibility, particularly in the northern and eastern areas of Mardan. This study offers spatial insights aimed at fostering evidence-based planning for equitable and sustainable development of green infrastructure in intensively developing areas.

Keywords Green spaces, Spatial analysis, Integrated assessment, GIS, Per Capita provision

1 Introduction

Green spaces are increasingly recognized as an essential component of the urban environment due to their multifaceted contributions to human well-being and ecological sustainability. Globally, these spaces have been shown to positively impact physical and mental health, promote social cohesion, and support biodiversity (Ellis, 2015; Kabisch & Haase, 2014) The provision of equitable and accessible green spaces is a critical factor in shaping urban sustainability and liveability (Wheeler, 2013), offering a range of environmental, social, and economic benefits to urban residents (Swanwick et al., 2003). However, in recent decades, rapid urbanization has led to a considerable reduction in urban green spaces across the globe. This decline is largely attributed to population growth, which fuels demand for housing and infrastructure at the expense of natural areas (Ajmi et al., 2023; Giles-Corti et al., 2005; Mwendwa & Giliba, 2012). In addition to urban sprawl, other contributing factors include inadequate financial investments, poor governance, limited public participation, and weak institutional frameworks (Rahman & Zhang, 2018). The issue is particularly acute in developing countries, where urban growth is projected

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to surge, with an estimated 1 billion people expected to reside in cities by the end of the twenty-first century (Raziq et al., 2016). This projection underlines the urgency of ensuring equitable access to urban services, including green spaces, which are not only vital for sustainability but also for public health and social equity. Yet, the rapid and often unplanned urban development in these contexts frequently results in unequal distribution and limited accessibility to such resources.

Despite the growing recognition of green space benefits, conventional assessments have primarily focused on quantitative indicators such as total green area or green space per capita, often overlooking the critical aspect of spatial accessibility (Wang et al., 2021). Such measures, while useful, fail to capture how the physical distribution of green spaces interacts with the urban form and transportation networks to influence accessibility for different population groups. In cities like Mardan—one of the major urbanized centres in Khyber Pakhtunkhwa, rapid urban expansion has placed immense strain on existing green infrastructure. Although a few local studies have acknowledged green space shortages in urban Pakistan, most have relied on limited data sources and static measurements, lacking integration of geographic and perceptual dimensions. The knowledge gap remains in understanding how green space provision aligns with population distribution and mobility patterns. Furthermore, the absence of spatially explicit data and robust methods for accessibility analysis continues to challenge the ability of planners and policymakers to design inclusive and equitable urban landscapes.

This study addresses these knowledge gaps by employing a mixed-methods approach that integrates qualitative insights, quantitative spatial metrics, and the Two-Step Floating Catchment Area (2SFCA) method to evaluate the provision of green space in Mardan City. The qualitative component captures residents' perceptions, preferences, and experiences related to local green spaces, providing a socio-cultural context to the spatial patterns. The quantitative analysis includes data on the size, location, and distribution of green spaces, as well as population densities across the city. The GIS-based model of the 2SFCA is widely used in spatial accessibility research, enabling the calculation of supply-to-demand ratios within predefined travel thresholds, thus providing a more dynamic and realistic representation of access. By synthesizing these approaches, the study aims to evaluate the current status of green space provision, assess spatial accessibility inequalities, identify underserved areas, and formulate context-specific recommendations for inclusive green space planning. The findings provide policy implications to urban planners, municipal authorities, and policymakers in developing evidence-based strategies to improve urban liveability and sustainability in Mardan City and similar rapidly growing urban areas.

This study applies a mixed-methods spatial assessment of urban green spaces in Mardan City. By integrating GIS-based spatial analysis, a quality index, and accessibility modelling, the study provides a holistic understanding of urban green spaces provision and equity. The specific objectives of this study are:

1. To map and quantify the spatial distribution of urban green spaces in the study area
2. Identify inequalities in provision, quality, and accessibility across neighborhoods of the city
3. Formulate policy-relevant recommendations for improving equitable access to green spaces in secondary cities.

Based on these objectives, the study seeks to answer the following research questions:

i. What is the spatial distribution and quality of urban green spaces in Mardan?
ii. What inequalities exist in the provision, quality, and accessibility of these green spaces?
iii. What lessons can Mardan's case offer for urban planning and policy in secondary cities?

2 Literature review

2.1 Green spaces provision standards – quantity and quality

Green spaces (GS) are essential for ensuring urban sustainability, public health, and social well-being. To achieve equitable access, many countries and international organizations have developed standards for green space provision based on three primary dimensions: quantity (total coverage), quality (condition and usability), and accessibility (spatial and social reach). These dimensions are deeply interconnected and together shape the equitable provision of GS.

The quantity standard pertains to the total green space area provided within urban settings and is frequently measured as green space per capita. The WHO sets a global benchmark of 9 m^2 of green space per person, which serves as a baseline for assessing green space provision in cities (WHO, 2017a). However, studies from developing regions determined that many urban areas provide far less than this standard, highlighting persistent spatial inequalities in green space availability (Olfato-Parojinog et al., 2024). This challenge is particularly relevant for secondary cities in South Asia, including Mardan. However, such a measure can be deceptive due to dynamic population densities and urban expansion.

For example, (Zhang et al., 2025) argue that a fixed per capita green space standard does not accurately reflect urban realities due to variations in built-up density across different city zones. According to the United Nations Environmental Programme (UNEP), a minimum of 10–20% of the city's area should be reserved for green spaces. While this benchmark offers a broad guideline, it may not be entirely reliable and often needs contextual adaptation based on cultural and environmental conditions. In Europe, cities with compact vertical development models allocate 30–40% of their urban area to green spaces, with some achieving up to 50% (Kafafy, 2010).

Similarly, the Quality, on the other hand, emphasizes the usability and aesthetic appeal of green spaces. This includes evaluating park size, design, landscape features, facilities, amenities, and levels of maintenance and safety. The Public Open Space Tool (POST), developed by (Broomhall et al., 2004), offers a structured approach to evaluate quality across four domains: activity features, environmental quality, comfort, and safety. The tool assesses elements such as recreational infrastructure, vegetation, seating areas, washrooms, lighting, and signage (Broomhall et al., 2004; Giles-Corti et al., 2005). High-quality green spaces are not only more attractive and usable but also enhance mental well-being and encourage more frequent usage.

2.2 Accessible green spaces

Accessibility is a vital dimension of green space provision, emphasizing the ease with which urban residents can access nearby green spaces. Proximity, travel distance, transportation options, and the presence of barriers significantly influence accessibility. Inadequate spatial distribution of green spaces often leads to disparities in access, especially in urbanising settlegreen spacesents of the regions. The Two-Step Floating Catchment Area (2SFCA) method, developed by (Zhang et al., 2022), is a prominent GIS technique for evaluating spatial accessibility. This approach calculates accessibility by considering both the supply of green spaces and the population demand within defined catchment areas. It also incorporates variable travel distances, service area sizes, and population densities, thereby capturing a more nuanced picture of accessibility.

In the rapidly growing urban centre of Mardan, this issue is particularly pronounced. Population growth and unregulated urban expansion have exerted pressure on existing green spaces, leading to fragmentation and limited accessibility. By integrating the 2SFCA method with qualitative insights and quantitative measures, this study aims to provide a holistic understanding of green space provision in Mardan. This integrated methodology will help identify underserved neighborhoods, highlight spatial disparities in accessibility, and offer practical recommendations for improving equitable access to green spaces. As cities like Mardan continue to grow, such data-driven planning tools become essential in promoting sustainable and inclusive urban development.

2.3 Volunteered geographic information and urban green space planning

The emergence of Volunteered Geographic Information (VGI) has introduced new dimensions to spatial data generation, democratizing access to geospatial technologies and fostering community participation in urban planning. Coined by (Goodchild, 2007). The term VGI refers to geographic data that is voluntarily contributed by individuals, often through online platforms, mobile applications, and social media. This user-generated content ranges from tagging locations to reporting land use changes, making it a valuable complement to traditional, top-down spatial datasets.

In the context of urban green space planning, VGI is increasingly discussed in the literature as a valuable tool, particularly in under-resourced or rapidly changing environments (Elwood et al., 2012). It enables more localized, real-time insights into the availability, condition, and use of green spaces and empowers communities to participate in monitoring and advocating for their neighborhoods. For example, OpenStreetMap has been widely used to map green infrastructure in developing cities, offering a low-cost, collaborative tool to supplement government records.

However, the integration of VGI into urban planning is a challenge. Concerns around data accuracy, completeness, and credibility are frequently cited. (Senaratne et al., 2017) categorize these data issues into three domains: positional accuracy, attribute reliability, and temporal consistency. Since contributions come from non-experts, the data may lack standardization or suffer from spatial bias, especially in areas with low digital literacy or internet access. Quality assurance mechanisms, such as cross-verification, reputation systems, and hybrid models compounding VGI with authoritative data, are increasingly being explored to overcome these limitations.

While this study did not incorporate VGI into its methodology, the reviewed literature highlights its potential as a valuable tool for participatory and inclusive assessment of green space in cities. Future research in cities like Mardan could benefit from combining VGI with GIS-based approaches such as 2SFCA and remote sensing, contributing to a more bottom-up and equitable model of green infrastructure planning.

3 Materials and methods

3.1 Study area

Mardan is the second most urbanised city in Khyber Pakhtunkhwa, Pakistan. It lies between 34° 05'–34° 32' North latitude and 71° 48'–72° 25' East longitude. Mardan is connected to the Malakand Division towards the Northwest, District Buner in the Northeast, District Nowshera in the Southeast, District Swabi to the East, and District Charsadda in the Southwest. The total area of the city is 142 sq. km. The recent development and better health and education facilities make this city attractive to migrants from its suburbs and rural areas. Since the inception of Pakistan, this city's population gradually increased from 13.6% in 1951 to 18% in 2023, while the housing stock increased from 8138 in 1951 to 63,333 in 2023 (Pakistan Bureau of Statistics (PBS), 2023).

District Madan's climatic condition is severe, with a cold winter and a hot summer. In Mardan, the winter season starts in mid-November and lasts until March. The coldest months of the year are December and January. In the coldest month of January, the minimum recorded temperature is −4°C and the mean minimum temperature of 2.1°C is also recorded for the same month. In District Mardan, summer starts from May to September. The highest maximum recorded temperature is 49.5°C for June, as the hottest month of the year, and the mean maximum temperature is also recorded for the same month is 40.2 °c. The maximum summer temperature generally surpasses 45 °C in the hottest month of June, and the minimum temperature goes below 1 °C during January, the coldest month of the year. Due to congested neighbourhoods and less planned green spaces in inner-city with high anthropogenic activities, the maximum temperature is high. Figure 1 shows the location map of the study area.

3.2 Data

3.2.1 Secondary data

This study incorporated diverse forms of secondary data, both spatial and non-spatial, obtained from reputable government agencies and global sources to support a comprehensive assessment of urban green space provision in Mardan City, Pakistan. The data played a central role in evaluating the qualitative characteristics,

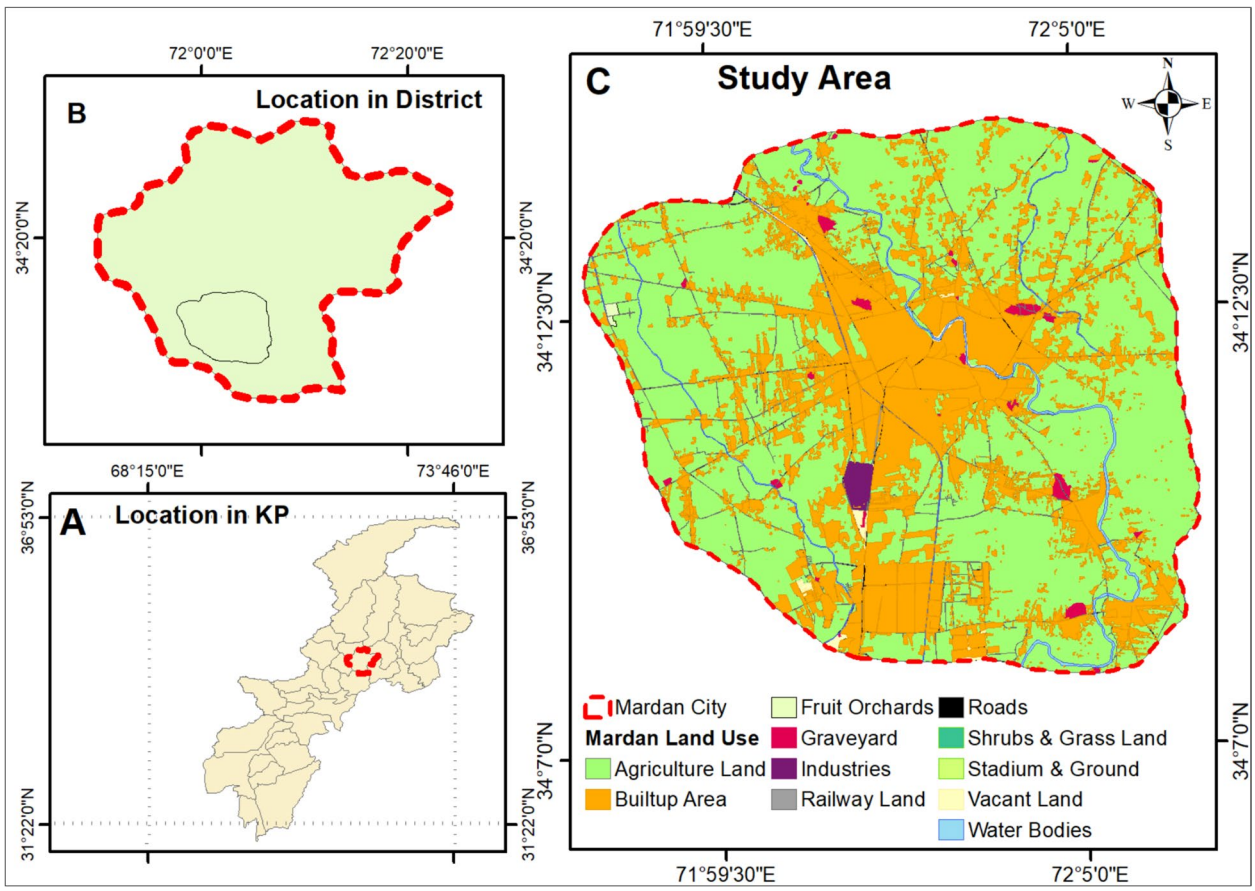

Fig. 1 Location Map of Mardan City in the District Mardan, Khyber Pakhtunkhwa Province, Pakistan

quantitative sufficiency, and spatial accessibility of green areas. Official datasets regarding the inventory, classification, and spatial distribution of green spaces and green spaces were collected from local development institutions, including the Tehsil Municipal Administration (TMA), Cantonment Board Mardan, Mardan Development Authority (MDA), and the Higher Education Department (HED). These institutions provided foundational information on the city's types, sizes, and administrative status of green spaces.

The population data were retrieved from the Pakistan Bureau of Statistics (PBS) for the year 2023 to analyse the demographic pressure and per capita green space availability. These datasets were used to calculate per capita green space availability in square meters (m^2) and help to determine whether green space provision met national and international benchmarks. For the geospatial dimension, high-resolution satellite imagery for the year 2023 was acquired from the United States Geological Survey (USGS) Earth Explorer. The imagery, primarily Landsat 8/9 and Sentinel-2, was processed to digitize green space boundaries, conduct land use and land cover (LULC) analysis, and measure total green area coverage across the urban fabric.

For the accessibility analysis component, the Two-Step Floating Catchment Area (2SFCA) method was applied using ArcGIS Pro's Origin–Destination (OD) Matrix tool. The spatial data for this analysis included digitized point and polygon features representing public green spaces, gardens, and recreational areas across Mardan. Each green space feature was attributed with key details such as its total area (measured in acres) and estimated service capacity (visitors per acre). Population data were available as polygon features corresponding to census blocks, enabling the evaluation of demand based on population density and distribution. A comprehensive road network dataset was utilized, including travel time and distance attributes, critical for modelling realistic service catchments and accessibility routes. Neighbourhood boundaries and city administrative boundaries were also incorporated to contextualize accessibility results within the urban framework. The attribute data supporting the 2SFCA method consisted of several key elements. First, population counts were used to represent the number of residents within each population unit. Second, the service capacity of green spaces was assessed, taking into account their size, available facilities, and carrying capacity (such as visitors per acre). Third, a travel time threshold was applied, defining the maximum acceptable travel distance or time to access green spaces. In this study, a 1000-m distance, approximately equivalent to a 10-min walk, was established based on international standards and local urban dynamics. This allowed for measuring the level of green space access across different neighborhoods and identifying underserved or disadvantaged zones.

Furthermore, the master plan of Mardan City for the period 2020–2040 was accessed from the Urban Policy and Planning Unit (UPU) of Khyber Pakhtunkhwa (UPPU., 2022). This document was instrumental in understanding the required and existing green space areas and supported the evaluation of future spatial priorities and service gaps. Additionally, secondary literature was extensively consulted to frame international and national standards for green space provision. Academic journals, planning guidelines, books, theses, and online resources were reviewed to extract qualitative criteria, i.e. safety, maintenance, accessibility, and recreational value. Institutional documents from UN-Habitat, the World Health Organization (WHO), and other global planning agencies were also consulted to inform the development of the assessment framework. Together, these secondary data sources provided a robust and multidimensional foundation for the integrated assessment of green space in Mardan City, guiding evidence-based planning and policy recommendations.

3.2.2 Survey data

To comprehensively assess the provision and quality of green spaces in Mardan City, a mixed-method approach involving field surveys, qualitative observation, and GPS-based spatial data collection was employed from March to May 2023. The aim was to collect data relevant to functional, aesthetic, and accessibility parameters of green spaces.

- *Survey Design and data collection*

  A structured checklist and field observation tool were developed to evaluate the functional and aesthetic qualities of green spaces. The checklist was designed after an extensive review of green space assessment frameworks (Kabisch et al., 2016; WHO, 2017b). The city was divided into administrative zones using neighbourhood boundaries. A purposive sampling approach was used to select 25 green spaces across Mardan City. The selection criteria included: (i) spatial distribution across different neighborhoods to ensure city-wide coverage, (ii) variation in size categories (small neighborhood parks, medium community parks, and larger city-level parks), (iii) diversity of management types (municipal, institutional, and privately managed), and (iv) levels of accessibility to the public. This approach ensured representation of the main types of green spaces available to residents. Based on the above criteria, the selected

green spaces fall under the jurisdiction of the Tehsil Municipal Administration (TMA), Mardan Development Authority (MDA), Cantonment Board Mardan, Private Housing Schemes and the Higher Education Authority. The sample includes a mix of formal green spaces, community green spaces, and semi-structured areas, distributed across both central and peripheral neighborhoods to capture spatial and institutional variation. The detailed data collection on provision, quality, and accessibility is discussed in the subsections below.

- *Quantitative and Spatial Data Collection*
  The ground-truthing and spatial analysis of the information obtained from the development authorities was cross-verified through field data collected. For this purpose, the GPS point data were collected using a Garmin eTrex 32x Global Positioning System, capturing the coordinates of each park's boundary, main entrance, internal pathways, and available amenities. These spatial data were exported into Microsoft Excel in XY format and subsequently integrated into ArcGIS Pro 3.0 for spatial analysis. This included land use and land cover (LULC) overlay, mapping of each park's location and size (in square meters), and assessment of proximity to built-up areas as well as distance to surrounding residential clusters. The processed spatial data also served as input for accessibility analysis through the Two-Step Floating Catchment Area (2SFCA) method.
- *Qualitative Observations and Indicators*
  To assess the quality of green spaces (GS), a comprehensive evaluation tool, the Green Space Quality Index, was developed. This tool was informed by three well-established quality assessment frameworks: the Public Open Space Tool (POST) (Taïbi et al., 2022), the Natural Environment Scoring Tool (NEST) (Allouche et al., 2022), and the Green Space Quality Assessment Tool (RECITAL) (Knobel et al., 2021). Drawing on the key indicators and methodological approaches from these sources, a structured checklist was designed to guide field assessments of green space quality, focusing on both functional and aesthetic attributes.

Subsequently, a purposive sampling technique was employed to ensure spatial representation and typological diversity across the study area. A total of 25 green spaces of varying sizes were selected, encompassing neighbourhood green spaces, community green spaces, and large green spaces. On-site qualitative evaluations were carried out by a team of three trained field surveyors, including one GIS specialist and two urban planning researchers, using the developed checklist to ensure consistency and reliability in data collection.

Functional indicators (e.g., seating, lighting, pathways, playgrounds, signage, and safety features) were assessed for their presence, condition, and maintenance level. Aesthetic indicators (e.g., vegetation diversity, landscape design, cleanliness, and visual appeal) were evaluated based on visual analysis and supported by photographic documentation. Each indicator was rated on a five-point scale: 0 (Very Poor), 25 (Poor), 50 (Fair), 75 (Good), and 100 (Excellent). These scores were assigned based on direct field observations, guided by predefined qualitative criteria and verified through cross-checking among team members to ensure inter-rater reliability.

No community members were recruited for evaluation purposes; instead, all observations were conducted by the research team. The GPS expert contributed to the spatial accuracy and geotagging of facilities within each park to support visual mapping and spatial correlation. The complete evaluation framework, including thematic categories and indicator descriptions, is detailed in Table 1.

3.3 Method

Figure 2 illustrates the comprehensive methodological flowchart used in this study to systematically investigate and analyze the research objectives. The flowchart outlines each step undertaken, from data collection and preprocessing to analysis and interpretation, to ensuring a structured and coherent approach to achieve the study's aims. Three different types of analyses were carried out in this study. The detailed methodology is provided below.

3.3.1 Quantitative assessment

The high-resolution satellite imagery was digitized to identify the existing land uses within the city. The locations of green spaces were overlaid to determine their spatial distribution. A comparison was made between two land-use classes, i.e. residential and green spaces, and the spatial distribution of green spaces was depicted on a map. This approach helps to understand the spatial allocation of population densities and the provision of green space within these localities.

Similarly, the per capita quantitative analysis of the study area was conducted by digitising all green spaces, following the methodology of Schüle et al. (2019), and as expressed by la Barrera et al. (2023). In this study, the concept of 'Per Capita Green Space Index (PCGSI) ' was introduced as the ratio of Green Space Area (GSA) to Total Population (TPo). Mathematically, the PCGSI is represented as follows:

$$PCGSI = GSA \div TPo$$

where PCGSI denotes the Per Capita Green Space Index; GSA denotes the Total Green Space Area (in square meters); TPo denotes the Total Population of the study

Table 1 Checklist of thematic areas used in the qualitative analysis, outlining the key dimensions and focus points assessed in the study

Theme	Indicator	Items Assessed	Scoring Type	Source of Information
Functional Amenities	Park Furniture	Benches, seats, canopies	Quantity and Quality	Field Visit
	Pathways	Type (paved/unpaved), connectivity, width	Quantity and Quality	Field Visit
	Entrance Arrangement	Number of entrances, signage, and accessibility	Quantity and Quality	Field Visit
	Security Arrangements	Presence of guards, fencing, and lighting	Yes/No	Field Visit
	Children's Amenities	Play equipment (slides, swings, etc.)	Quantity and Quality	Field Visit
	Sports Facilities	Courts, fields, and exercise equipment	Quantity and Quality	Field Visit
	Restrooms/Water Facilities	Drinking water, toilets, and sanitation	Quantity and Quality	Field Visit
Aesthetic Qualities	Vegetation Diversity	Tree/shrub variety, colour, texture	Quantity and Quality	Field Visit
	Cleanliness	Waste bins, litter presence, and maintenance	Quantity	Field Visit
	Visual Appeal	Landscape design, symmetry, harmony with surroundings	Qualitative Assessment	Field Visit
Accessibility	Proximity to Residences	Distance from nearest residential clusters	Spatial Distance (km)	GPS & GIS Analysis
	Connectivity	Road/pedestrian access, public transport availability	Qualitative Assessment	Field Visit & GIS
	Barrier Assessment	Presence of walls, fences, blocked paths	Yes/No	Field Visit
	Catchment Area Coverage	500 m & 1000 m buffer coverage using 2SFCA	GIS-Based	GPS, ArcGIS Pro 3.0

area. This index quantifies the per capita availability of green space within the study area. By employing the PCGSI, the aim is to evaluate the accessibility of green spaces to the population, providing a quantitative measure of the distribution of green space relative to the population. (Ibrahim & Ahmad, 2023a).

3.3.2 Qualitative assessment

The qualitative assessment of green spaces in this study was conducted using the Qualitative Green Space Index (QGSI), which evaluates functional amenities and aesthetic qualities to assess the overall quality of green spaces. The QGSI was developed based on existing literature and adapted to the study area's specific context (Zhao et al., 2024).

- *Scoring Procedure*

  A five-point scale (0%, 25%, 50%, 75%, and 100%) was used to evaluate each item in terms of both quality and quantity. The scoring criteria are explained in Table 2 below:
- *Weighting and Final Index Calculation*
  Each indicator was given a specific weight based on its importance in determining the overall quality of the green space. The weights applied were 0%, 25%, 50%, 75%, and 100%. The weighting for the QGSI was based on the functional necessity and user relevance of specific features within green spaces. Functional indicators—such as seating, lighting, safety, and pathways- were prioritised because they directly affect usability, comfort, and safety, making them essential for everyday park use. Aesthetic indicators, while also important, were assigned relatively lower weight due to their subjective nature and lesser impact on the functionality of green spaces. The QGSI was created using multiple indicators grouped into dimensions of accessibility, amenities, safety, ecological value, and maintenance. Weights were assigned to each indicator to reflect their relative importance in shaping user experience and ecological function. The weighting process followed two steps: (i) a review of prior studies that developed quality indices for urban green spaces, and (ii) consultation with three local urban planning and landscape experts to adapt these weights to the context of Mardan. For example, the functional amenities were given slightly more evaluative emphasis to reflect their critical role in promoting inclusive, active, and safe public space use based on user perception and actual use, consistent with previous studies (Chen et al., 2020; Kabisch & Haase, 2014; Maruani & Amit-Cohen, 2007). To ensure consistency in qualitative scoring, inter-rater reliability was planned using Fleiss' Kappa, as it is suitable for assessing agreement among three raters. This approach enabled us to statistically measure the level of agreement in the QGSI evaluations across all sampled parks. By integrating these criteria, scoring procedures, and data collection methods, the QGSI effectively evaluates the qualitative aspects of green spaces, offering a comprehensive understanding of their functional and aesthetic conditions. These

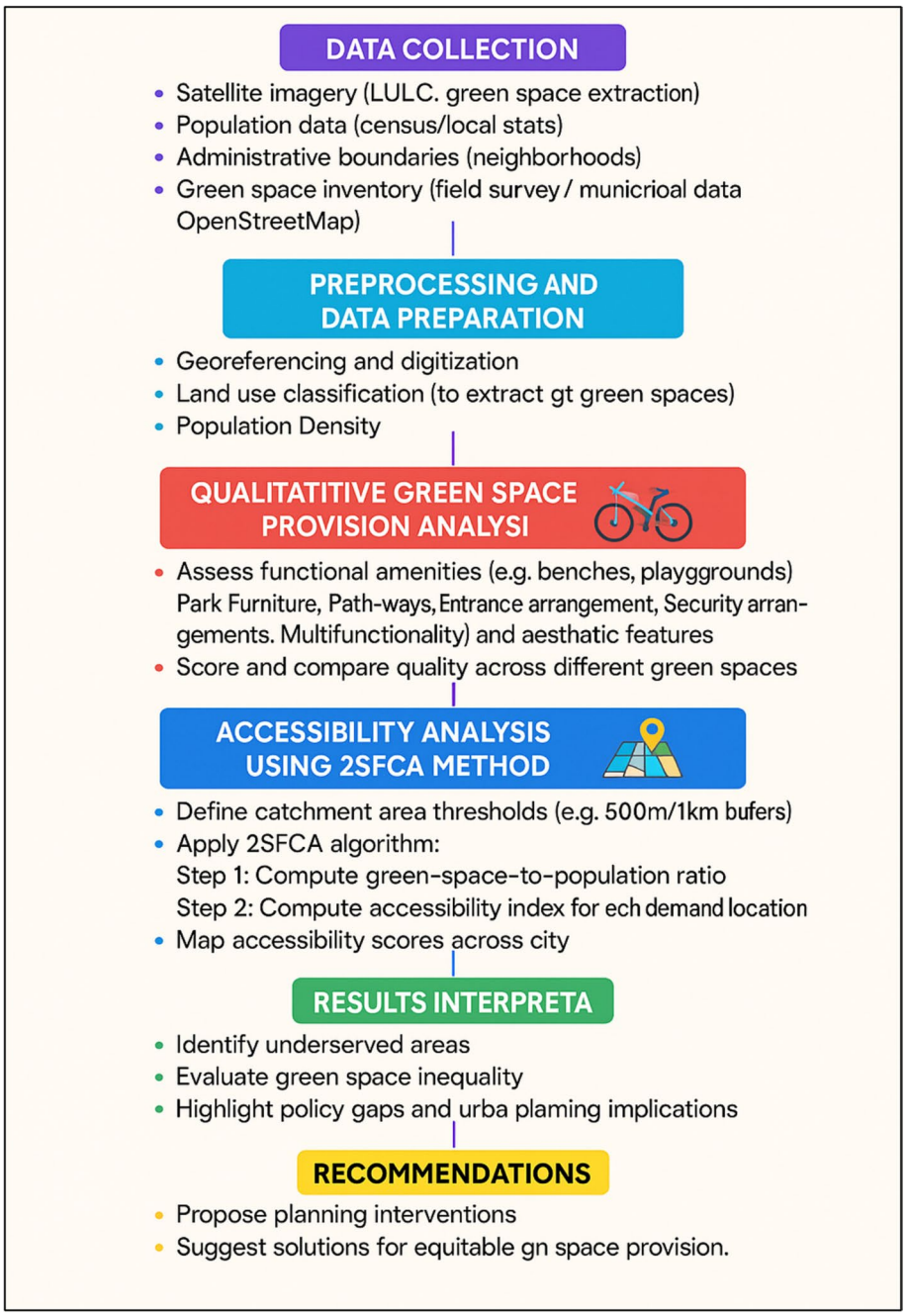

Fig. 2 Flowchart illustrating the research methodology

context-specific adjustments ensured that the QGSI captured both international standards and local priorities.

3.3.3 Accessibility assessment

The Two-Step Floating Catchment Area (2SFCA) method is a widely used GIS-based technique for evaluating spatial accessibility (Wang & Sadahiro, 2024). This method integrates supply and demand within defined travel thresholds to measure accessibility. The following methodology outlines the data requirements, formulas, and step-by-step procedure to implement the 2SFCA method using ArcGIS Pro with the Origin–Destination (OD) Matrix tool. The methodology adopted for the accessibility analysis is discussed below. The 2SFCA method involves two key steps:

Table 2 Scoring criteria for the Green Space Quality Index (GSQ-Index), showing the indicators used, scoring levels, and corresponding score ranges

Type of Scoring	0%	25%	50%	75%	100%
Quantity and quality	Not present	Not fit for purpose	Suitable but in need of repair or insufficient quantity	Suitable and sufficient	Suitable, sufficient, and aesthetically pleasing
Yes/no	No	––	––	––	Yes
Quality	Bad	Poorly maintained and aesthetically unpleasant	Poorly maintained or aesthetically unpleasant	Well-maintained and aesthetically pleasing	Exceptionally well-maintained and aesthetically pleasing

Source: (Ajmi et al., 2023)

Table 3 Historical Land Use of Mardan City, 2023

S. No	Land Use Type	Area in Acres	Percentage (%)
1	Parks and playgrounds	307	0.87
2	Agriculture	14,680	41.79
3	Commercial	761	2.17
4	Graveyard	265	0.75
5	Industries	27	0.08
6	Public Buildings	905	2.58
7	Railway Land	45	0.13
8	Residential	16,951	48.26
9	Roads	700	1.99
10	Vacant Land	120	0.34
11	Water Bodies	365	1.04
	Grand Total	**35,126**	**100.00**

Step 1: Calculating Supply-to-Demand Ratio for Each Green Space

In this step, the supply-to-demand ratio for each green space is calculated based on the number of people within a defined travel threshold. The Origin–Destination (OD) Matrix tool is employed to calculate the travel distance or time between green spaces, considered as supply points, and residential areas, considered as demand points. A travel threshold is then set, which is 1000 m for walking distance or a 2-km buffer for driving distance, to define the accessible range. The 1-km walking and 2-km driving thresholds used in the 2SFCA method were based on a combination of international accessibility standards (European Environment Agency, 2016; WHO, 2017b) and context-specific considerations observed during fieldwork in Mardan. The 1-km threshold approximates a 10–12-min walk, aligning with global recommendations for walkable access to urban green spaces. The 2-km driving threshold reflects local urban mobility constraints and is commonly used in prior South Asian accessibility studies (Liu et al., 2023). For the 2SFCA model, a 1 km walking and 2 km driving threshold were applied to estimate service catchment areas. These thresholds were selected based on both local travel behavior and supporting literature. Field observations and survey responses in Mardan revealed that most residents were willing to walk up to 10–15 min (approximately 800–1000 m) to reach nearby facilities, a finding consistent with those from similar South Asian urban contexts (Butt & Rigoni, 2025; Rahman & Zhang, 2018). The 2 km driving threshold reflects typical short-distance trips in secondary Pakistani cities, where motorbike and rickshaw use is prevalent for local travel (Hasan & Ukkusuri, 2015; Imran & Low, 2005). These thresholds thus combine local evidence with international benchmarks for walkable and drivable distances, ensuring contextual relevance for Mardan.

Within this defined threshold, all population points (demand locations) that fall within the catchment area of each green space (supply) are identified. Subsequently, the supply-to-demand ratio is calculated using a standard formula, where the total area or capacity of the green space is divided by the sum of the population within its catchment. This ratio reflects the per capita availability of green space within the defined travel threshold and serves as a basis for determining spatial accessibility levels across different parts of the city.

$$Rj = \frac{Sj}{\sum i \in dij \leq doPi}$$

where Rj denotes the supply-to-demand ratio at green space; Sj denotes the capacity of green space J (e.g., area in hectares or visitor capacity); Pi denotes the population at the demand point i. The summation includes all population points i within the threshold distance d0 from green space j, where dij is the network-based distance between locations i and j. This ratio shows how much green space is available per person within the catchment area of each green space.

Step 2: Calculating Accessibility Score for Each Demand Point

This step assigns an accessibility score to each population point based on its proximity to nearby green spaces.

For each demand point, all green spaces located within the defined travel threshold were identified. The supply-to-demand ratios of all accessible green spaces were then summed to determine the cumulative accessibility. Finally, the accessibility score for each demand point was calculated using the established formula, which incorporates both the spatial distribution of supply (green spaces) and demand (population) within the specified catchment area.

$$Ai = \sum_{j \in \{dij \leq do\}} Rj$$

where the Ai represents the accessibility score for a population location i, calculated by summing the supply-to-demand ratios Rj of all green spaces j within a network distance dij less than or equal to the threshold do (e.g., 1000 m). Here, Rj reflects the capacity of green space j relative to the local population demand, dij is the distance between population and green space locations, and do defines the maximum travel distance considered accessible.

The 2SFCA method was implemented in ArcGIS Pro to assess green space accessibility across Mardan City. Initially, the required spatial datasets—including road network data, green space locations, and population distribution points—were imported into ArcGIS Pro, ensuring all layers shared a common coordinate system to maintain consistency in distance calculations. Using the Network Analyst extension, a network dataset was constructed from the road network, integrating travel time and distance attributes to support accurate accessibility modelling. The OD (Origin–Destination) Cost Matrix tool was then utilized, designating green spaces as origins and population points as destinations. A travel threshold—such as a 1000-m buffer or a 10-min walking distance—was defined to generate the OD matrix, which computed travel distances or times between each origin and destination pair.

Following the matrix creation, supply-to-demand ratios were calculated by joining the OD matrix results with the population dataset to determine the total population served within each green space's catchment area. The ratio was computed using a standardized formula that considered green space capacity relative to surrounding population demand. These ratios were then linked back to the population points to derive individual accessibility scores, using a second formula that summed available green space opportunities weighted by supply-to-demand ratios. Finally, the accessibility scores were visualized through choropleth and graduated symbol maps to identify areas with high or low access to green spaces. Hot spot analysis was also conducted to detect statistically significant clusters of accessibility disparities, providing a spatial understanding of green space equity across the city.

3.3.4 Data limitation

The study depended on municipal datasets obtained from the Mardan Municipal Authority and other local government departments. While these datasets provided crucial baseline information on land use, green spaces, and administrative units, several limitations were identified. Firstly, inaccuracies, missing records, and non-digitised documentation reduced the precision of quantitative assessments. Additionally, the datasets were not regularly updated, meaning recent land-use changes and newly developed green spaces were not reflected. Secondly, inconsistencies in classification across departments required further verification through field surveys. Thirdly, the spatial resolution of some maps was limited, which could have affected the accuracy of boundary delineations. To mitigate these issues, municipal data was supplemented with field observations, GPS mapping, and satellite imagery cross-checks to improve reliability.

4 Results

4.1 Historical land use of Mardan City

Mardan is a medium-sized city located in Khyber Pakhtunkhwa. It is encircled by a ring road, covering a total area of 35,126 acres. The city exhibits the characteristics of urbanized neighborhoods, featuring a high population growth rate and considerable development of built-up areas across its various administrative units. Some neighborhoods are situated in the city's center, while others have emerged as newer residential societies along the ring road. The ongoing increase in urbanization is leading to several challenges, including overcrowding and environmental degradation. The city contains diverse land uses. The residential area spans approximately 16,951 acres, making up 48.26% of the total city area. Parks and playgrounds (green spaces) cover 307 acres, constituting only 0.87% of the city's area. In comparison, the commercial area encompasses 761 acres, which is 2.17% of the total city. Industrial land accounts for 27 acres, while public buildings occupy 905 acres, and 265 acres are designated for graveyards. Water bodies cover 365 acres, and 120 acres are designated as vacant land. Roads extend over 700 acres, with 45 acres occupied by railway lines. The land use distribution in the city shows a clear imbalance between residential development and supporting uses such as green spaces. Nearly half the city's area is devoted to housing, while parks and playgrounds

account for less than 1%. This imbalance reflects rapid built-up expansion at the expense of recreational and ecological needs, contributing to overcrowding, congestion, and environmental stress. The findings highlight the need for integrated planning strategies that promote balanced land use, expand green space, and guide sustainable growth along the ring road. Historical land use with percentages is shown in Table 3 and Fig. 3.

4.2 Comparative analysis of residential and green spaces in Mardan City

There is a noticeable imbalance in the distribution of built-up areas and green spaces in Mardan. Urban expansion, particularly towards the ring road, has led to a significant reduction in available green spaces, with some areas lacking them entirely. This issue is especially prominent in the western parts of the city, where green spaces are almost non-existent. According to land use data from 2023, residential areas occupy approximately 16,951 acres, which accounts for about 48.26% of the total urban footprint. In stark contrast, only 307 acres—or a mere 0.87%—of the city's area is designated to green space. This disparity highlights a severe under-provision of public green areas relative to the residential spread. With a population density of around 12 persons per acre, and considering national planning standards that recommend allocating at least 12% of urban land for green spaces in areas with a density of 20 persons per acre, Mardan falls significantly short of the required benchmark. This shortfall not only affects environmental quality but also limits opportunities for recreation, social interaction, and mental well-being among residents. Figure 4 presents a detailed spatial and quantitative analysis of this imbalance.

4.2.1 Existing green spaces

The existing green space data were identified through field surveys. There is a total of 38 green spaces in the city. These green spaces fall under the jurisdiction of different authorities in the city. The Tehsil Municipal Administration (TMA) has ten parcels of green spaces under its jurisdiction with a total area of 302,675 sq.m. The Mardan Development Authority (MDA) managed 13 green spaces having a total area of 206,249 sq.m. Cantonment Board Mardan (CBM) has 6 different types of green spaces under its jurisdiction. The rest of the recreational facilities were provided by Government Departments, i-e, Educational Institutions and the Directorate of Sports

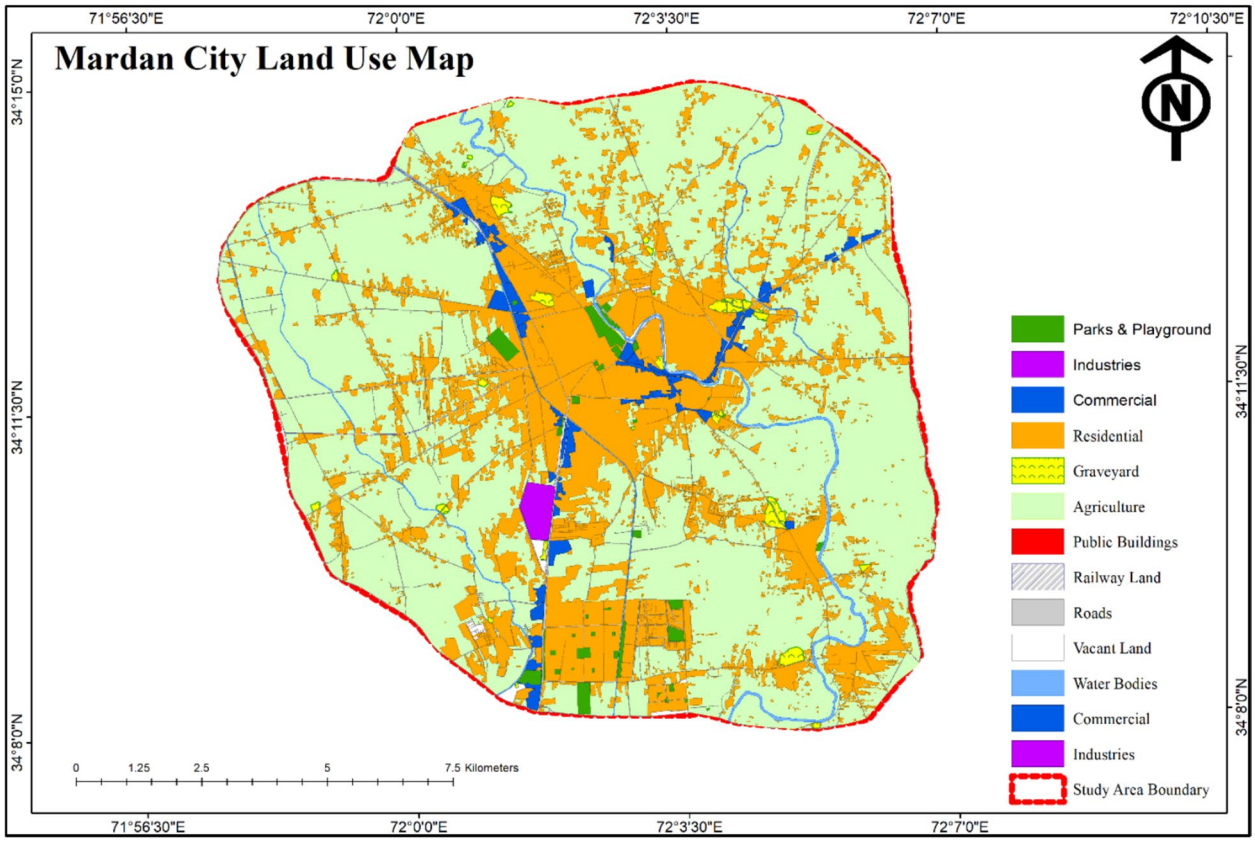

Fig. 3 Existing land use of Mardan City, showing the distribution of major land use categories

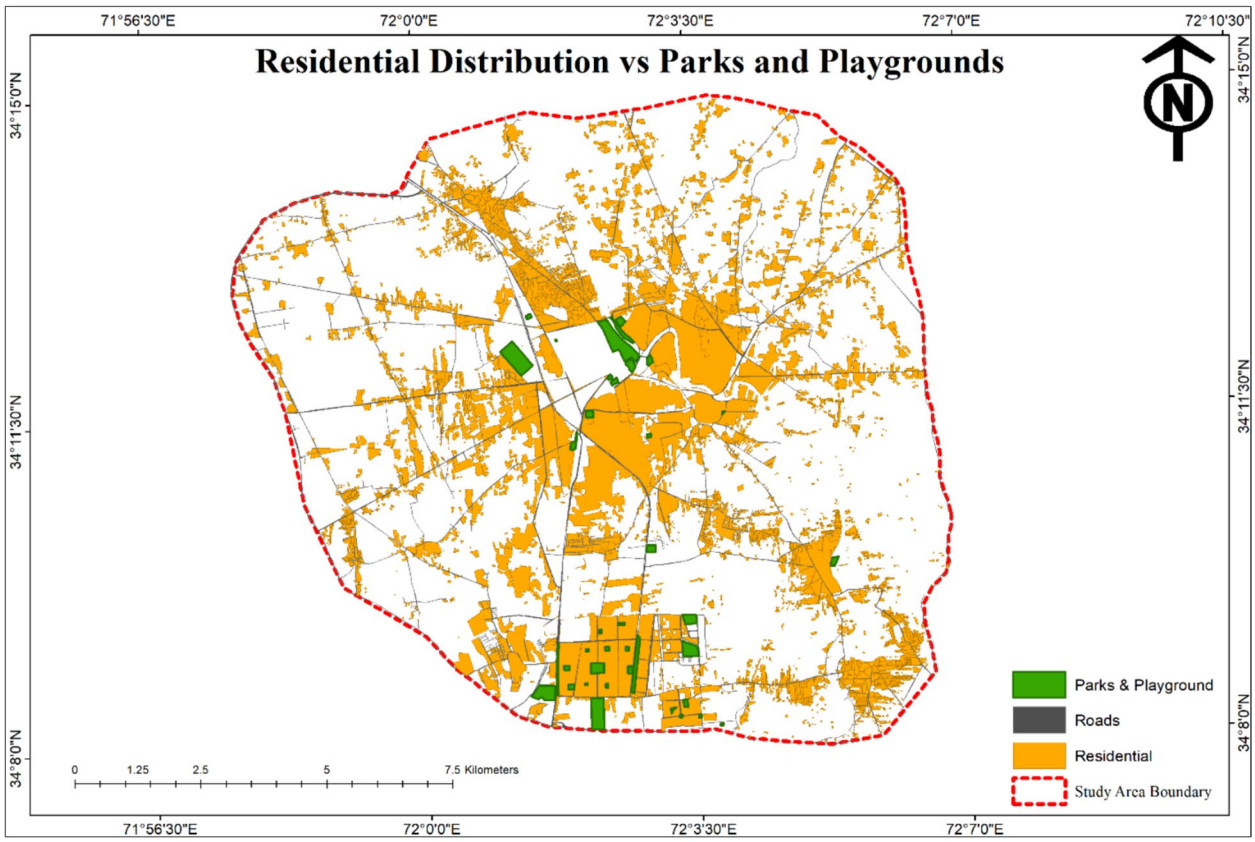

Fig. 4 Spatial distribution of residential areas and green spaces in Mardan City

in the city. This fragmented management and uneven distribution reflect weak coordination in urban green space planning. Strengthening institutional collaboration and ensuring equitable provision are critical for improving recreational access and urban livability. The spatial distribution of green spaces is shown in Fig. 5.

4.3 Quantitative analysis of green spaces

City livability depends on its social, economic, and environmental settings, and the provision of adequate green spaces plays a pivotal role in creating sustainable and healthy urban environments. Both the World Health Organisation (WHO) and the Food and Agriculture Organisation (FAO) recommend a minimum of 9 square meters of green space per resident to ensure urban sustainability and livability (WHO, 2017b). Similarly, Pakistan's National Reference Manual on Planning and Infrastructure Standards (PEPAC, 1985) sets a national benchmark of 5.2 square meters per inhabitant. However, the current situation in Mardan City reveals a concerning shortfall. Based on the 2023 population census, which reports a total population of approximately 1,254,003, and the available green space of 404,000 square meters, the per capita green space stands at just 3.1 square meters. This is 2.1 square meters below the national standard and 5.9 square meters below the international standard. Such a deficiency indicates a critical need for the expansion and equitable distribution of green infrastructure across the city to meet not only planning benchmarks but also the health and well-being needs of its growing population. This significant shortfall underscores the urgent need for urban planning interventions that expand and equitably distribute green infrastructure to align with both national and international benchmarks and support the well-being of the city's growing population.

A comparative spatial analysis of per capita green space is illustrated in Fig. 6.

4.4 Qualitative analysis of green spaces

According to the GSQ-Index, a theme-based analysis of green spaces was carried out. The analysis shows a varying degree of effectiveness across different authorities in the city. The Tehsil Municipal Administration (TMA) scored 48.4% for functional amenities and 52% for aesthetic qualities, indicating a need for significant improvements in both areas. The Mardan Development Authority (MDA) performed better, with 70% for

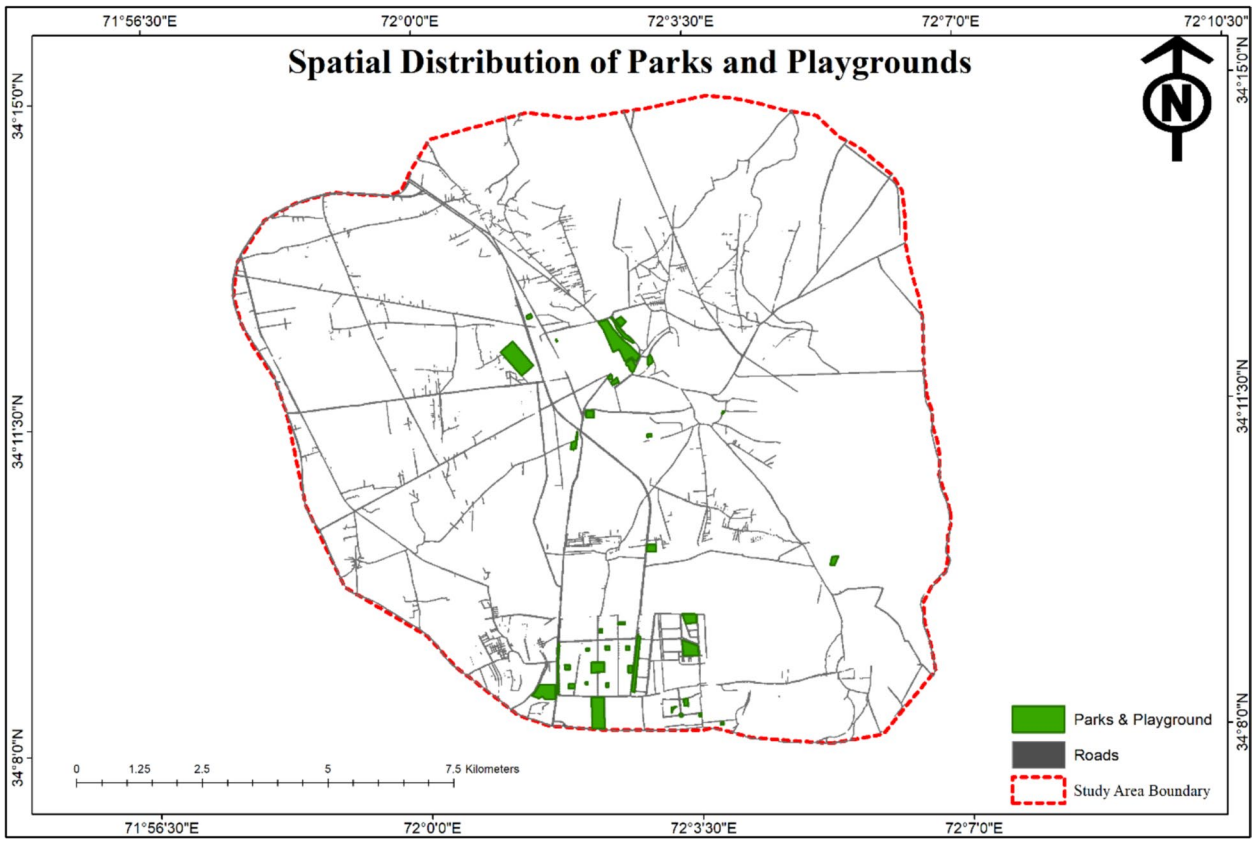

Fig. 5 Location map of dedicated green spaces in Mardan City

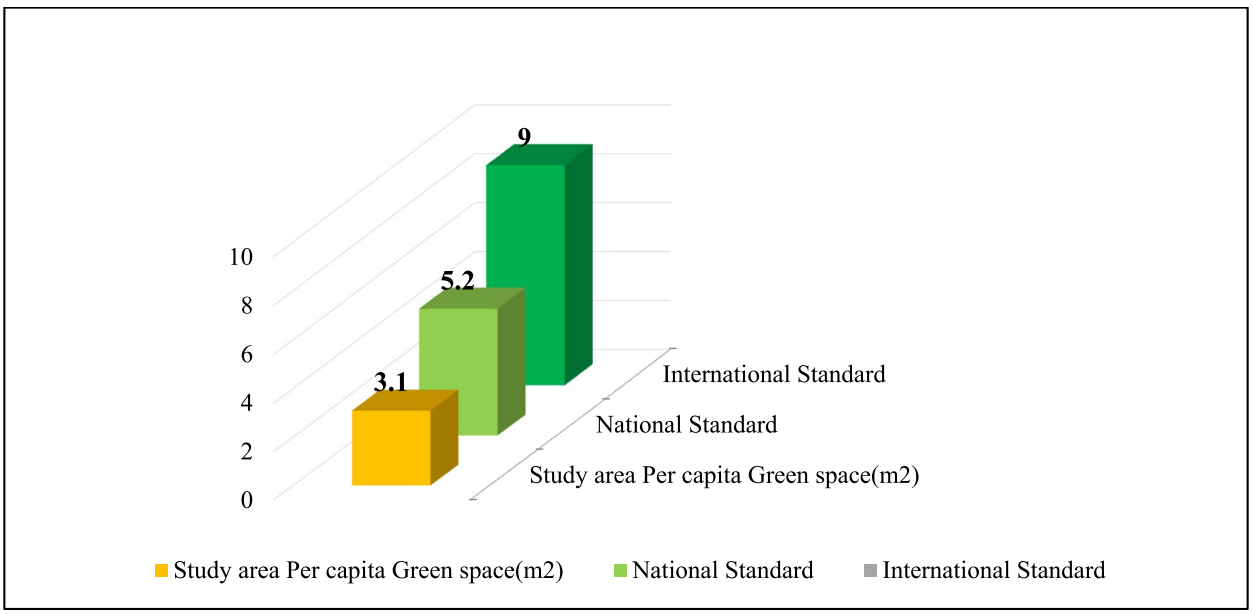

Fig. 6 Graphical representation of per capita green spaces in Mardan City

functional amenities and 78% for aesthetic qualities, suggesting effective maintenance and design practices. The Cantonment Board Mardan scored 62% for functional amenities and 66% for aesthetic qualities, showing moderate success but room for enhancement. Private housing societies demonstrated a good level of functional amenities at 65.5%, but need improvement in aesthetic qualities, scoring 58%. The Higher Education Authority led with the highest scores, achieving 71.3% for functional amenities and 81% for aesthetic qualities, showcasing superior management and visual appeal of their green spaces.

To ensure the consistency and validity of qualitative scoring across the 25 assessed parks, inter-rater reliability was evaluated using Fleiss' Kappa, which is suitable for three raters. The analysis produced a kappa value of 0.52, indicating moderate agreement(Landis & Koch, 1977). This result reflects the effectiveness of pre-assessment calibration sessions and standardised scoring procedures employed during field evaluations. The moderate level of agreement enhances confidence in the reliability of the QGSI scores presented in this section.

These results highlight the disparity in the quality and management of green spaces across different jurisdictions, emphasizing the need for targeted interventions to enhance the quality of green spaces. This tool, with detailed information, may help urban planners and policymakers sustain and encourage green space management to make our cities livable and sustainable. The GSQ-Index results reveal significant variation in the quality of green spaces across managing authorities, highlighting uneven standards of provision and maintenance. The results will also help to promote the protection and development of green spaces in rapidly developing cities, as well as the management and usability of these spaces. For urban planning, this underscores the need for coordinated strategies and targeted improvements to ensure consistent, high-quality green infrastructure that supports livability and sustainability in Mardan. A summary of functional and aesthetic scores across different managing authorities is presented in Table 4.

Table 4 QGSI-based functional and aesthetic scores of green spaces by the managing authority in Mardan

Managing Authority	Functional Score (%)	Aesthetic Score (%)
Tehsil Municipal Admin. (TMA)	48.4	52.0
Mardan Development Authority (MDA)	70.0	78.0
Cantonment Board Mardan	62.0	66.0
Private Housing Societies	65.5	58.0
Higher Education Authority	71.3	81.0

4.5 Accessibility analysis of green spaces via 2SFCA method

The accessibility of green spaces across the city was assessed through GIS-based analysis, i.e. Two-Step Floating Catchment Area (2SFCA). Figure 7 shows the accessibility analysis result with the graduated color scheme, where darker shades indicate higher accessibility, and lighter shades signal lower accessibility. Accessibility values in the analysis ranged from 0 (low) to 1 (high), highlighting a clear spatial disparity in the distribution of green spaces. The southern part of the city, particularly the southwest, exhibits significantly higher accessibility to green spaces, as indicated by the dark brown and red tones. This suggests a concentration of well-distributed green spaces serving a relatively smaller population or a high number of accessible green spaces in proximity. The central areas demonstrate moderate accessibility, indicating a balanced relationship between green space availability and population density. In contrast, the northern and eastern zones are characterized by low accessibility values, illustrated in light yellow shades. These areas are underserved and likely lack sufficient green spaces or are located at greater distances from available green spaces, worsened by higher population concentrations.

This uneven distribution of accessibility highlights spatial inequality in green space provisioning. It underscores the necessity for targeted urban planning interventions, particularly in the northern and eastern peripheries, to enhance equitable access to green spaces and recreational areas. The use of both 1 km and 10 km catchment thresholds in the 2SFCA analysis allows for assessing accessibility at both neighborhood and regional levels, while considering walking and vehicular access. This analysis emphasizes the importance of integrating accessibility metrics into urban development strategies to promote inclusive and sustainable city planning. Figure 7 shows the spatial accessibility to the green spaces within the city.

The overall results indicate that while central neighborhoods have relatively better provision of green spaces, peripheral areas are underserved. This spatial inequality has important implications for urban planning, highlighting the need for targeted investments in expanding green infrastructure in rapidly growing fringe settlements.

4.6 Challenges and management issues of green spaces

The qualitative, quantitative and accessibility analysis shows that the existing facilities are fewer in quantity as compared to national and international standards. It has also been observed that these facilities are in bad condition, particularly in the areas under the jurisdiction of the Tehsil Municipal Administration. Mardan Development Authority has well-maintained, dedicated green

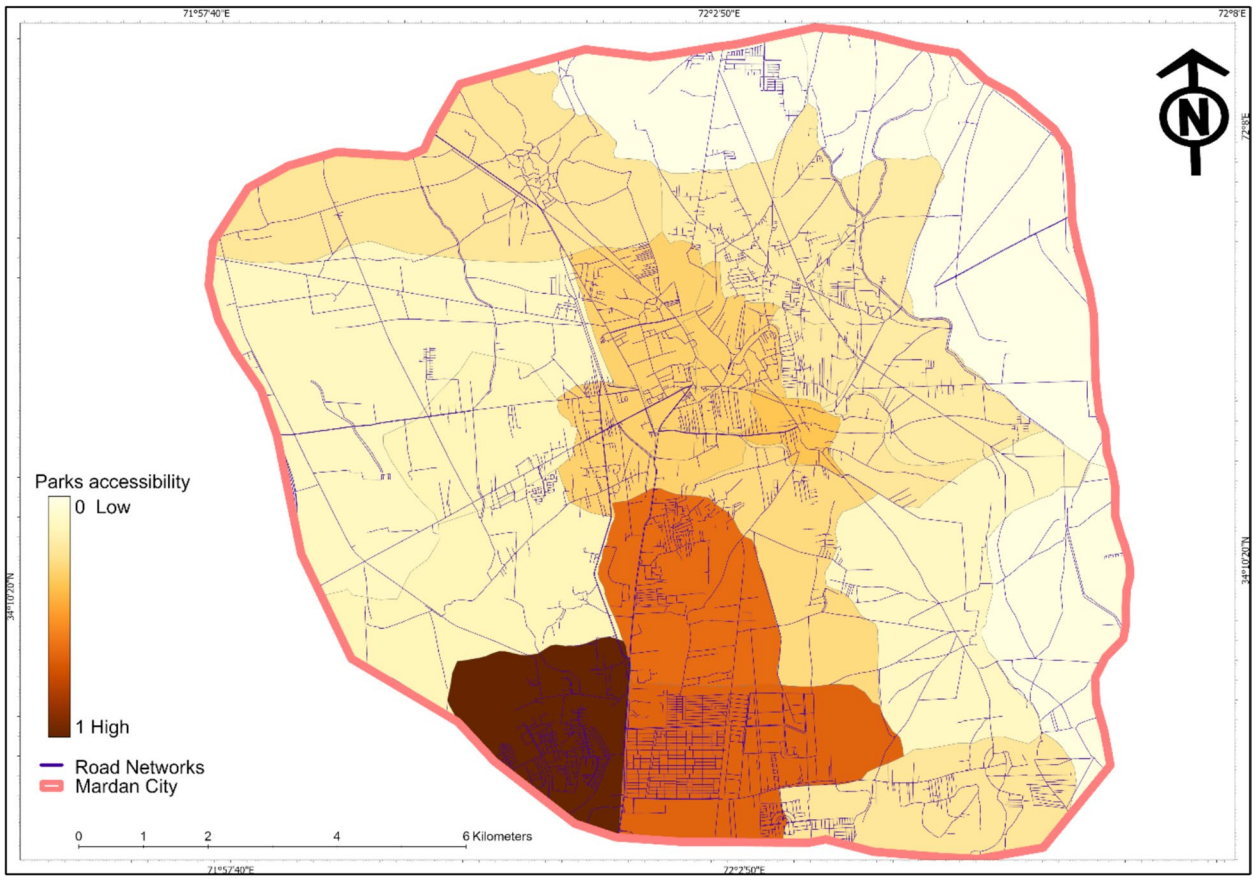

Fig. 7 Park Accessibility in Mardan City using 2SFCA Method

spaces according to greenery, but lacks some basic facilities. The Mardan Cantonment green spaces are few with good maintenance and facilities, i.e. canopies, benches, dustbins, etc. Besides this, these green spaces and playgrounds are not gender inclusive; there is no provision of safety measures for female visitors to the green spaces, and no designated areas for females. The above analysis has determined that there is ineffectiveness in the management of green spaces within the jurisdiction of development authorities. The following are some of the key issues in the management of these green spaces.

The data provided by the municipal authority regarding green spaces in the study area were found to be rough and unreliable, making it inadequate for monitoring quantitative standards or ensuring sufficient provision. A comparison of official figures with actual site conditions revealed discrepancies, as several spaces classified as green areas—such as Azi Khel Park and Ghulam Nabi Park—had not yet been developed with vegetation or facilities typically associated with public green spaces. The absence of computerised documentation within the Tehsil Municipal Administration (TMA) further complicates accurate assessments; current statistics remain paper-based, and no systematic spatial data exists to track or manage the green spaces under their jurisdiction. As a result, the reported figures not only miscalculate the quantity of green space provided but also overlook significant portions of land that could be categorized as green areas. Observations revealed that many green spaces managed by the TMA were in a state of disrepair, reflecting a broader governance issue. Interviews with municipal officials linked these conditions to budgetary constraints, lack of institutional motivation, and, most critically, the low priority given to green spaces by decision-makers. Officials expressed the view that enhanced funding, expert involvement, and trained maintenance staff could substantially improve the quality and accessibility of these spaces. Ghulam Nabi Park, in particular, was cited as a case of severe neglect, characterized by insufficient facilities such as benches and signage, a generally unclean environment, and poor vegetation. As illustrated in Fig. 8, the park exemplifies the consequences of inadequate maintenance and systemic oversight.

Fig. 8 A poorly managed park in Mardan City, illustrating inadequate maintenance and facilities. Source: The Author

5 Discussion

5.1 Brief summary of key findings

This study comprehensively examined the quantity, quality, and accessibility of green spaces to assess their contribution to the livability and sustainability of Mardan City. The analysis revealed critical deficiencies across all three dimensions. The per capita green space provision stands at merely 3.1 m^2, which falls drastically short of both national and international standards recommending a minimum of 9 m^2 per person (WHO, 2017b). Land-use analysis exhibited that only 0.87% of the total land is dedicated to green spaces, significantly below the recommended 5–10% allocation. Furthermore, qualitative assessments highlighted poor maintenance, lack of essential amenities (such as benches, canopies, and dustbins), absence of gender inclusivity, and inadequate safety measures. Spatial accessibility analysis revealed that a majority of the population does not have easy access to these spaces, with uneven distribution favouring certain parts of the city over others. Administrative inefficiencies, poor data management, and a low prioritisation of green space development were also identified as key challenges, particularly within the jurisdiction of the Tehsil Municipal Administration (TMA). These findings collectively point toward the urgent need for strategic reforms in the planning, development, and management of green spaces.

5.1.1 Linking to the literature

The findings of this study enrich the current literature with empirical evidence in the Pakistan context, which has been rarely covered previously. Our findings are consistent with some observations in the Global South and developing countries, which highlight the critical deficiencies in green space provision across rapidly urbanising regions.

Scholars such as (Kabisch et al., 2016) and (Haaland & van Den Bosch, 2015) have emphasised how the rapid pace of urbanisation often results in a prioritization of grey infrastructure—roads, buildings, and utilities—over green infrastructure. This trade-off is particularly pronounced in developing countries, where urban planning frameworks struggle to keep pace with demographic and spatial expansion. In Pakistan, similar patterns have been observed in metropolitan areas such as Karachi and Lahore. (Rana & Bhatti, 2018) report that Lahore's green spaces are fragmented and often inaccessible, while (Qureshi et al., 2010) find that green areas in Karachi are inequitably distributed and lack integration into broader planning strategies.

Similar challenges have been documented in other rapidly growing South Asian and Pakistani cities. For example, (Ibrahim & Ahmad, 2023b) analyzed green space provision in Peshawar and found that only 2% of the urban land was allocated to dedicated green spaces, compared to 54% built-up area. The study reported a per capita green space availability of 1.5 m^2, which falls significantly below both national (5 m^2) and WHO (9 m^2) standards. This aligns with our findings in Mardan, where green coverage is similarly limited and unevenly distributed. A similar approach has been applied in Dhaka, Bangladesh, where green spaces were assessed through the lens of multisensory experience and mental restoration. A study by (Tabassum, 2025) emphasized the importance of sensory diversity—including soundscapes, visual design, and tactile features—in shaping user comfort and well-being across two distinct parks in Gulshan and Mohammadpur. Despite Lahore's seemingly high value of ~ 25 m^2 in affluent areas like Gulberg Town, citywide green space accounts for only ~ 0.66% of the urban area, with access heavily skewed toward higher-income neighborhoods (Alam, 2014). While Mardan lacks such multisensory planning, the observed deficits in green space quality and aesthetic design point to comparable barriers to user engagement and mental relief. Accessibility issues across these cities share common traits: green spaces are unevenly distributed, poorly connected, and often absent in low-income zones. Mardan mirrors these regional challenges, reinforcing that spatial equity and user-centered design must become core priorities in urban green planning across cities. This underlines the need not only for equitable access but also for qualitatively rich, inclusive green space experiences in secondary cities across South Asia. Table 5 summarizes key green space (GS) indicators of various regional cities, including Mardan.

Together, these comparative studies support the broader challenges faced by secondary cities across South Asia, i.e. low green space availability, unequal access, and the need to tactically invest in both biodiversity and

Table 5 Comparative UGS Indicators in Selected South Asian Cities

City	Green Space per Capita (m^2)	% of Urban Area	Accessibility Issues	Source
Mardan	3.1	0.87%	Uneven access; peripheral zones are underserved	This study
Peshawar	1.5	2%	Low access in informal settlements	Ibrahim and Ahmad (2023a, 2023b)
Lahore	~25 (Gulberg Town example)	~0.66% (citywide parks)	Unequal, disconnected, affluent-biased green access	(Alam, 2014)
Dhaka	~1.1	< 5%	Highly unequal access; poor sensory experience	Tabassum. (2025)
WHO	9	—	—	(WHO, 2017b)

equitable spatial provision within the cities. These findings underscore a national trend of diminishing green space amid urban expansion, and they mirror the situation in Mardan, where green space provision is similarly inadequate and unevenly distributed.

However, the situation in Mardan presents several additional challenges that distinguish it from larger cities. Unlike cities where public–private partnerships or civil society initiatives have partially mitigated gaps in green space provision, as seen in various cities of India, (Sinha et al., 2024) Mardan demonstrates minimal private sector involvement in environmental or recreational infrastructure. Moreover, institutional weaknesses in data governance further compound the issue. A significant barrier identified in this study is the absence of digitised and reliable urban data, which hinders evidence-based decision-making and long-term planning. These challenges are reflective of broader systemic governance issues, including limited planning capacity, under-resourced municipal institutions, and the neglect of secondary cities in national urban development agendas. Strengthening data systems, enhancing inter-agency coordination, and encouraging community participation are thus essential steps toward addressing these persistent gaps in cities like Mardan.

While this study relied primarily on municipal datasets and field surveys, the findings highlight the potential for integrating Volunteered Geographic Information (VGI) into future urban green space assessments. VGI, such as community mapping or user-generated reports, could help address gaps in municipal data by capturing informal or newly established green spaces and providing real-time insights into quality and accessibility. For secondary cities like Mardan, where official datasets are often outdated or incomplete, VGI offers a cost-effective and participatory tool to complement traditional data sources and strengthen evidence-based planning.

5.2 Policy implications

The findings of this study highlight several policy implications for improving urban green space planning in Mardan. Firstly, there is an urgent need to increase the total area allocated to public green spaces, targeting 5–10% of the urban land, consistent with national urban planning benchmarks. Green spaces should be integrated into master plans and future urban expansions, especially in underserved neighborhoods. Secondly, spatial equity must be prioritized by ensuring an even distribution of green spaces across all socio-economic zones. Accessibility targets—such as a 1000-m walkable buffer—should guide location decisions so that no community is left behind in terms of proximity and reach. Thirdly, the green spaces should be designed to be gender-inclusive and safe, with proper lighting, visible security, child-friendly amenities, and accessibility features for vulnerable groups. Encouraging diverse use by women, children, the elderly, and people with disabilities must be a core goal of park design. Fourthly, quality assessments reveal significant deficiencies in amenities and maintenance. Addressing this requires short-term measures such as community-based maintenance programs and the upgrading of basic facilities including lighting, benches, and sanitation. Over the longer term, city-wide quality standards that incorporate both ecological and social indicators should be developed to ensure consistent service delivery. Fifthly, the Municipal bodies should invest in digitizing green space inventories and adopt GIS-based monitoring tools to support decision-making and ensure transparency. Regular audits, community feedback mechanisms, and open-access data portals can foster accountability and trust. Lastly, the Municipal governments should explore public–private partnerships (PPPs) to finance the creation and maintenance of green spaces. Simultaneously, there is a need to train municipal staff in landscape architecture, urban ecology, and community engagement to ensure sustainable green space management. Collectively, these recommendations can help cities like Mardan become more resilient, livable, and equitable.

5.3 Limitations and future research directions

While the study offers important insights, it is not without limitations. First, the reliability of green space data provided by municipal authorities was a major challenge.

Inaccuracies, missing records, and non-digitized documentation limited the precision of quantitative assessments. Future studies should prioritize primary data collection using remote sensing and GIS-based methods to map and monitor green spaces more accurately (Li et al., 2024). While municipal datasets were the primary source of spatial information, their accuracy may vary due to outdated records or limited standardization. Although field verification and manual cross-checking were applied where feasible, future studies could benefit from integrating remote sensing tools (e.g., Landsat-based NDVI) and community-sourced platforms such as OpenStreetMap to enhance data completeness and reliability. These sources offer an independent means of validating mapped features, particularly in rapidly changing or informal urban areas.

Secondly, while this study employed qualitative field surveys, the absence of community input may have introduced bias, particularly in assessing aesthetic and experiential qualities. The moderate inter-rater agreement (Fleiss' Kappa = 0.52) reflects the inherent subjectivity of QGSI scoring, despite calibration efforts. Future studies should consider refining scoring criteria and incorporating community-based surveys or participatory assessments to better capture diverse user perceptions, especially around safety, accessibility, and inclusivity. Moreover, while this study focused primarily on formally designated green spaces, informal green elements—such as street trees, road verges, and vacant plots—can play a significant role in enhancing urban greenery, particularly in low-resource settings like Mardan. These small-scale or unregulated green areas often provide essential ecosystem services, shade, cooling effects, and even psychological relief in densely built-up neighborhoods. Although they were not quantitatively assessed in this study due to classification and data limitations, future research could explore their contribution to overall green space provision and equity using high-resolution imagery, field mapping, or participatory GIS approaches. Future research could also benefit from incorporating remote sensing tools, such as the Normalised Difference Vegetation Index (NDVI), to analyze long-term trends in urban vegetation cover and seasonal variation in green space health. NDVI data derived from high-resolution satellite imagery can offer a more dynamic, temporal perspective on green space quality that complements field-based assessments.

Thirdly, the integration of Participatory GIS (PGIS) approaches could help bridge the gap between technical analysis and lived experience. Engaging local communities in mapping exercises, spatial storytelling, and digital participatory tools would enable a more inclusive understanding of how different groups perceive, access, and use green spaces. This dual approach—combining objective satellite-based data with subjective community knowledge—can enhance the accuracy, relevance, and equity of future green space planning, particularly in highly urbanising cities like Mardan. Longitudinal studies are also necessary to monitor changes over time and to assess the effectiveness of urban policies and interventions on green space provision.

Lastly, this study primarily focused on GIS-based spatial analysis and did not employ Volunteered Geographic Information (VGI), which is a methodological limitation. VGI offers a promising participatory dimension that can enrich urban green space assessments by incorporating local knowledge and user experiences. However, due to the unavailability of structured VGI data in Mardan and the study's focus on secondary data sources, it was not feasible to incorporate VGI in the current analysis. Future research could address this gap by including VGI through citizen mapping initiatives or mobile-based participatory platforms, thereby improving the inclusiveness and responsiveness of urban green space planning. Finally, comparative studies involving other secondary cities across Pakistan would provide a broader understanding of green space challenges and inform national-level planning.

6 Conclusion

In conclusion, this study, using Mardan as a pilot case, sheds light on the pressing issue of inadequate green space provision in Pakistan's rapidly urbanizing secondary cities. Through a combination of spatial analysis and qualitative assessment, it identifies major gaps in the distribution, accessibility, and quality of green spaces, benchmarking them against national and international standards. Although focused on one city, the methodology and findings provide a replicable model applicable to other urban areas in Pakistan. The insights gained here can guide planners, municipal authorities, and policymakers in promoting equitable access to green infrastructure, enhancing urban livability, and aligning development with sustainability goals. This research thus contributes meaningfully to the national urban planning discourse and underscores the need for data-driven, inclusive strategies to address the growing ecological and social challenges faced by cities across the country.

Authors' contributions

Muhammad Ibrahim: Conceptualization; Methodology; Formal analysis; Data Curation; Investigation; Writing – Original Draft; Writing – Review &; Editing; Visualization; Project Administration. Siqin Wang: Conceptualization; Methodology; Software; Validation; Formal analysis; Data Curation; Investigation; Writing – Original Draft; Visualization; Project Administration; Supervision. Shaokun Lyu: Data Curation; Software. Niaz Ahmad: Writing – Review &

Editing; Supervision; Validation. Muhammad Jamal Nasir: Writing – Review & Editing; Supervision.

Funding
This research received no external funding.

Data availability
The authors do not have permission to share the data.

Declarations

Competing interest
The authors declare no competing interests.

Received: 21 June 2025 Revised: 8 September 2025 Accepted: 27 October 2025
Published online: 05 November 2025

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