EVALUATING THE QUALITY OF WALKABILITY IN PEDESTRIAN ENVIRONMENTS IN TSUKUBA, JAPAN USING THE PEDESTRIAN ENVIRONMENTAL QUALITY INDEX (PEQI)

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Abstract: As global urbanization accelerates, enhancing urban liveability becomes increasingly important, with walkability being a crucial dimension. This study evaluates the current state of walkability in Tsukuba City, Japan, using the Pedestrian Environmental Quality Index (PEQI). Tsukuba City, despite its innovative planning and efficient public transportation, faces increased car dependency and rapid urban development, necessitating a reassessment of its pedestrian infrastructure. By analysing factors such as intersection safety, vehicular traffic, sidewalks, land use, safety and aesthetic qualities and perceived walkability, this research aims to provide a comprehensive, evidence-based evaluation of Tsukuba City's pedestrian environment. The findings reveal that most intersections and segments assessed offer reasonable conditions, though there is substantial room for improvement. The findings are intended to inform urban planning practices, enhance public health, promote environmental sustainability, and provide economic benefits. This comprehensive assessment offers a model for similar analyses in other urban contexts.

Keywords: *Walkability, Pedestrian Environmental Quality, PEQI, Tsukuba City, Japan*

1. Introduction

As global urbanization accelerates, enhancing urban livability becomes increasingly important. A key aspect of this is mobility—the ease with which residents can access various services and amenities (Natera Orozco et al., 2020). Walkability, a key dimension of urban mobility, refers to how conducive an environment is for walking, encompassing factors such as safety, comfort, and overall pedestrian friendliness (Nakamura, 2022). High walkability not only promotes physical health, supports environmental sustainability and also fosters social interaction and cohesion.

In Japan, urban planning has traditionally prioritized efficient public transportation and compact city layouts. However, the nation faces unique challenges, including a declining and aging population, which necessitates a reevaluation of urban planning strategies (Hino et al., 2022). Tsukuba City, located in Ibaraki Prefecture, serves as a compelling case study in this context. Established in the 1960s as a hub for scientific research and development, Tsukuba City has evolved into a vibrant urban center with over 150 research institutions and numerous Research & Development companies. This growth has attracted a diverse population, including students, professionals, and families. Despite its innovative planning and the introduction of the Tsukuba Express high-speed train in 2005, which boosted the city's appeal, Tsukuba has become increasingly car dependent (Thapa & Murayama, 2009a). This shift, coupled with rapid urban development and a rising population density, underscores the need to evaluate how well Tsukuba City supports pedestrian activity.

Currently, the effectiveness of Tsukuba City's walkability infrastructure remains underexplored, creating a gap in understanding its impact on urban livability. By raising the question, **"What is the current state of the quality of walkability in Tsukuba City, Japan?"**, this research aims to provide an evidence-based, comprehensive analysis of the city's pedestrian environment. The Pedestrian Environmental Quality Index (PEQI) will be employed as the primary framework for this analysis. The PEQI offers a holistic, structured, and quantitative approach to evaluating walkability in pedestrian environments across multiple dimensions. The original PEQI parameters include intersection safety, traffic, street design, land use, and perceived safety (San Francisco Department of Public Health, 2008).

Despite Tsukuba City's planned nature, this study anticipates uncovering discrepancies between the city's original design and contemporary pedestrian needs. Insights from this research are expected to inform urban planning practices, enhance public health outcomes, promote environmental sustainability, and offer economic benefits. Furthermore, this research will provide an evidence-based guide for conducting similar analyses across various neighbourhoods in the city, aiming for a large-scale assessment of the quality of walkability. This comprehensive approach seeks to deliver actionable insights that can shape future urban planning and policy-making efforts.

1.1. RESEARCH OBJECTIVES

- To address the main research question, the following objectives have been established:

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- Assess the current state of the quality of walkability in Tsukuba City using the PEQI.
- Identify and analyse the key factors influencing the quality of walkability in Tsukuba City as indicated by the PEQI.
- Determine areas with high and low quality of walkability using PEQI scores, highlighting regions that excel or require improvement.
- Provide actionable recommendations for urban planning and design enhancements based on PEQI findings to improve the quality of walkability in Tsukuba City.

1.2. LIMITATIONS AND SCOPE

The research scope was narrowed by focusing on a 1 km^2 area centered on the Tsukuba City Center, considering time constraints and aiming for a more comprehensive analysis. Also, the study will be constrained by the subjective nature of perceived factors, which may affect the accuracy of the PEQI scores. Additionally, the focus on Tsukuba City means that the findings may not be generalizable to other cities with different urban characteristics. Despite these limitations, the research aims to offer valuable insights into the quality of walkability of Tsukuba City and provide actionable recommendations for urban improvement.

2. Literature Review

2.1. WALKABILITY AND ITS ROLE IN ENHANCING URBAN LIVEABILITY

Walkability refers to how conducive the built environment is for pedestrian mobility, encompassing factors such as safety, comfort, and overall pedestrian friendliness (Nakamura, 2022). Traditionally, pedestrians were defined as individuals traveling by foot, but this definition has recently expanded to include those using wheelchairs or other assistive devices (Lo, 2009). Creating a walkable urban space requires analyzing several physical environments, including pedestrian sidewalks, accessibility to amenities, and environmental conditions (Baobeid et al., 2021). In contemporary urban planning, walkability is a crucial indicator of urban livability, reflecting the quality of life in cities through health, environmental, and social dimensions (Baobeid et al., 2021). Walkable cities promote physical activity, crucial for preventing lifestyle-related diseases, and increase overall public health (Baobeid et al., 2021; Brownson et al., 2009; Cutts et al., 2009; Giles-Corti et al., 2016; Fonseca et al., 2022). They also reduce reliance on automobiles, lowering greenhouse gas emissions and supporting environmental sustainability with green spaces (Baobeid et al., 2021). Socially, walkable areas enhance community interaction and cohesion by hosting more social activities and fostering a stronger sense of community (Leyden, 2003). Therefore, investing in pedestrian infrastructure and urban design that prioritizes walkability is essential for the future of livable urban environments.

2.2. METHODS FOR ASSESSING WALKABILITY

Walkability is a multifaceted concept that requires a thorough evaluation of both objective and subjective data to gauge its quality effectively (Saadi et al., 2021). Objective data involves measuring physical characteristics of the environment, such as the presence of sidewalks, crossings, and signals, using audit-based tools and checklists. This data helps identify areas needing improvement to enhance walkability for all pedestrians. In contrast, subjective data focuses on people's perceptions and experiences of walking within a given environment. Additionally, recent advancements in technology, such as mobile apps and GIS, have revolutionized walkability assessments by enabling real-time data collection and creating interactive maps and visualizations. These tools enhance the understanding of walkability dynamics and facilitate more responsive urban planning (Murray et al., 2019; Rodrigues et al., 2018). To comprehensively evaluate walkability, various assessment tools employ diverse indicators and methodologies, including objective, subjective, and mixed approaches. For instance, the Irvine–Minnesota Inventory assesses factors like traffic safety, personal security, attractiveness, social environment, and amenities (Dragović et al., 2023). The Neighborhood Environment Walkability Scale (NEWS) evaluates land use, connectivity, aesthetics, and pedestrian safety at the neighborhood level (Weiss et al., 2010; Brownson et al., 2004). Tools like Pedestrian Environmental Data Scan (PEDS) examines land use, network structure, collision aspects, safety, and security (Clifton et al., 2007), while the Pedestrian Environment Quality Index (PEQI) covers intersection safety, traffic, street design, land use, and perceived safety (San Francisco Department of Public Health, 2008). The variety in these tools allows researchers to tailor assessments to specific objectives and environmental contexts, guiding improvements in infrastructure and fostering pedestrian-friendly, healthy, and sustainable urban environments.

2.3. PEDESTRIAN ENVIRONMENTAL QUALITY INDEX (PEQI)

Efforts to enhance walkability greatly depend on the quality of pedestrian environments. These efforts are significantly more effective when they incorporate an analytical tool that identifies areas with the greatest need for improvement and proposes specific methods to address barriers to walkability (City of Austin Planning Department, n.d.). In this regard, this research utilizes PEQI as a valuable tool for assessing the current state of the quality of walkability in Tsukuba City. As developed by the San Francisco Department of Public Health (SFDPH), the original PEQI consists of five domains: intersection safety, (motor vehicle) traffic, street design, land use, and perceived safety; observed with respective to the intersections and street segments as follows (San Francisco Department of Public Health, 2008). Each indicator in PEQI holds assigned values contributing to the final score.

Table 1: Original PEQI Indicators for Intersections by Domain

1. Intersection Safety	**Assesses intersection features that enhance pedestrian access and mobility while alerting oncoming traffic at pedestrian crossings** (San Francisco Department of Public Health, 2008)**.**
a. Crosswalk, Ladder Crosswalk	Marked crosswalks indicate the possibility of pedestrians crossing, aiding vehicle awareness. The absence of crosswalks can hinder pedestrian movement and crossing from one side of the street to another.
b. Pedestrian and traffic Signal, Crossing Speed	Adequate signal timing is crucial for pedestrian safety. Short crosswalk timers can hinder movement and create hazards if pedestrians are still crossing when the signals change.
c. Crosswalk Scramble	Allows pedestrians to cross in all directions, including diagonally across an intersection. This minimizes conflicts between pedestrians and traffic, making it suitable for areas with high pedestrian volumes.
d. No Turn on Red Signs	Restrictions on right turn on red (RTOR), especially during peak pedestrian activity and at specific times, is effective in increasing the number of vehicles that come to a complete stop before making the turn. This also reduces the percentage of pedestrians who yield to right-turning vehicles and may still be crossing the street when the traffic light changes for oncoming traffic. This helps eliminate potential conflicts between vehicles and pedestrians.
e. Traffic Calming Feature	Physical features that reduce the negative impact of motor vehicles use by slowing their speed. PEQI differentiates between traffic calming features at intersections and those along streets. Ex: Curb extensions or bulb-outs, partial mini-circles, partial street closures, speed tables, roundabouts, pavement treatment, and semi-diverters.
f. Additional Signs for Pedestrians	These signs inform pedestrians about wayfinding and changes in traffic control. Additionally, they can effectively raise driver awareness, serving as a cost-effective method to draw attention to pedestrians and assist them in safely crossing intersections or walking along sidewalks.

Table 2: Original PEQI Indicators for Segments by Domain

2. Traffic	**Measures factors that are predictive of exposure distance for pedestrian, conflict points, pedestrian injury severity and pedestrian mobility** (San Francisco Department of Public Health, 2008)**.**
a. Number of lanes	The number of vehicle lanes influences traffic volume, speed limits, pedestrian activity, and social capital in a neighbourhood. Pedestrian injuries tend to increase with more lanes, but reducing lanes can decrease crossing distances and improve perceived safety.
b. Two-way traffic	One-way streets with multiple lanes can lead to higher vehicle speeds and increased potential for vehicle-pedestrian conflicts. Research shows that injury rates are higher on one-way streets than in two-way streets.
c. Vehicle speed limit	Vehicle speed is crucial in determining pedestrian injury severity. The fatality rate for a pedestrian struck by a vehicle moving at 20 mph is approximately 5%, but it increases to 45% at 30 mph - 85% at 40 mph.
d. Traffic volume	A significant predictor of pedestrian injuries in vehicle-pedestrian collisions. High traffic volume not only increases the risk of pedestrian injuries but also discourages pedestrians from crossing streets.
e. Traffic calming features	Ex: Chicanes, speed humps, medians, rumble strips, and street enforcements. They improve safety and slow traffic movement along the street, creating a safer environment for pedestrians and vehicles.
3. Street Design	**Measures sidewalks features, pertains to the physical layout and features of streets** (San Francisco Department of Public Health, 2008)**.**
a. Sidewalk width	Determines the level of safety and comfort for pedestrians walking down the streets.
b. Sidewalk impediments, obstructions	Sidewalk conditions and obstructions significantly impact pedestrian safety and comfort. Unobstructed, well-maintained sidewalks are crucial for a safe walking environment.
c. Presence of curb	Serve as a physical barrier separating motor vehicles from pedestrians, discouraging parking on sidewalks, and preventing vehicles from mounting curbs, enhancing pedestrian safety, and reducing obstructions.
d. Driveway cuts	Driveway cuts in street segments increase the likelihood of vehicles obstructing pedestrians and create potential conflict points.
e. Trees, Planters/gardens	The urban landscape significantly influences the walking experience. Natural elements, such as trees, enhance aesthetics and provide a buffer between pedestrians and vehicle traffic. Planters and gardens contribute to urban design quality, making streets more attractive for pedestrians.
f. Public seating	Public seating promotes leisure walks. Incorporating street amenities, like benches, bicycle parking, and street vendors, increases physical activity and pedestrian safety.
g. Presence of buffer	Bicycle lanes and parallel parking act as buffers between pedestrians and motor vehicles, contributing to pedestrian safety. Having a two-to-three-foot buffer provides pedestrian comfort and safety.

4. Land Use	**Measures commercial uses and street aesthetics. Considers how the surrounding built environment supports the mobility of pedestrians** (San Francisco Department of Public Health, 2008).
a. Storefronts/retail use	Diverse and mixed land uses promote proximity between residences, employment, and services, reducing vehicle trips and encouraging active transportation.
b. Public art/historical site	Artistic and cultural amenities can enhance the visual appeal and attract pedestrians. Factors such as the presence of historic buildings and public art contribute to the overall urban design quality for pedestrians.
5. Perceived Safety	**Informed by how physical features of an environment shape people's perceptions of safety and therefore their willingness or comfort with walking** (San Francisco Department of Public Health, 2008).
a. Illegal graffiti; Litter; Pedestrian scale lighting	Perceived safety is influenced by the physical environment, including factors like no illegal graffiti, litter, and having adequate pedestrian scale lighting.
b. Construction sites	Construction sites can disrupt pedestrian flow and pose safety hazards by blocking sidewalks and creating fewer accommodating routes. They can also contribute to noise pollution, impacting the walking experience.
c. Abandoned buildings:	Abandoned buildings signal negligence, contributing to pedestrian discomfort, fears of crime, and less visual appeal.

2.4. APPLICATIONS OF PEDESTRIAN ENVIRONMENTAL QUALITY INDEX (PEQI) IN URBAN PLANNING

The Pedestrian Environmental Quality Index (PEQI) has demonstrated significant adaptability and utility in urban planning across various contexts. Its flexibility allows for the integration of specific indicators and adjustments in weightings to reflect local conditions (San Francisco Department of Public Health, 2008; Sousa et al., 2019). Sousa et al. (2019) adapted PEQI for Portuguese cities, customizing it based on case studies like Covilhã, while the National Association of City Transportation Officials [NACTO] (2015) tailored PEQI for Los Angeles' Boyle Heights, addressing urban fabric differences. Dharmasena et al. (2025) used PEQI framework in the Sri Lankan context, applied to assess the quality of pedestrian environment for differently abled people in the Pettah public transport district. Additionally, PEQI's compatibility with Geographic Information Systems (GIS) enhances its applicability by enabling detailed spatial analysis and visualization of walkability scores (Sousa et al., 2019). GIS facilitates the identification of spatial trends and patterns, aiding in targeted improvements and effective communication with stakeholders. This adaptability and spatial analysis capability underscore PEQI's value in advancing urban planning approaches for pedestrian-friendly environments.

2.5 PREVIOUS STUDIES ON WALKABILITY IN TSUKUBA CITY AND THE RATIONALE FOR USING PEQI

Previous studies on walkability in Tsukuba City have largely relied on spatial modelling and visualization techniques to understand the distribution of walkable areas across the city. Thapa & Murayama (2009b) developed a Walkability WebGIS platform that mapped pedestrian-friendly zones and accessibility levels. Although effective for visualizing walkable networks, their approach provided limited insight into the experiential and qualitative aspects of pedestrian environments. Lwin & Murayama (2011) further advanced this line of research by constructing an eco-friendly walk score model using web-based GIS and satellite imagery to assess walkability in relation to green spaces. However, this method remained data-driven, focusing mainly on spatial parameters rather than the lived experience of walking. Similarly, Koohsari et al. (2018) employed Walk Score® to measure neighbourhood walkability based on proximity to amenities and street connectivity, yet the index lacked the sensitivity to local environmental characteristics and design qualities that influence pedestrian comfort and safety.

Given these limitations, the current research adopts the Pedestrian Environmental Quality Index (PEQI) to assess walkability in Tsukuba City. Unlike GIS-based or model-driven approaches, PEQI integrates field-based observations with environmental quality indicators, allowing for a more comprehensive and context-sensitive evaluation of pedestrian environments. This makes it possible not only to identify where walkability is low but also to understand which physical or perceptual factors contribute to those outcomes. Therefore, employing PEQI in the Tsukuba City is expected to generate actionable insights for improving pedestrian infrastructure and urban design quality.

The PEQI was originally developed as a practical tool to quantify pedestrian infrastructure quality and safety issues impacting pedestrian behaviour. PEQI is based on a standardized visual inspection protocol that assists in quantifying street segment and intersection conditions that influence pedestrian perceptions of safety, comfort, and aesthetics (San Francisco DPH, 2008). Though PEQI was developed for an American urban context initially, in the current study, the model applies to Tsukuba City, Japan, with consideration of different contexts like urban planning policies, pedestrian culture, and transportation norms unique to Tsukuba. Sousa et al., (2019) highlighted that the flexibility of the index for easy integration for a new area-specific indicators and adjustable weights by applying this to Portuguese Medium-Sized Cities. The NACTO (2015) modified the original PEQI framework to suit the streets of Los Angeles. Dharmasena et al., (2025) have utilized the modified PEQI framework in Pettah-Colombo city, Sri Lanka, by excluding the indicators like 'pedestrian scrambles' and 'public art' in their research study as they are of lower applicability to the chosen user category and site conditions.

The PEQI tool used in various situations across the globe are a reflection of the universal applicability of the said tool for evaluating the quality of pedestrians' walkable environment. Dharmasena et al., (2025) used the baseline weightage values in their research in Colombo, Sri Lanka because of the global applicability of PEQI. Therefore, the weightage values used in the NACTO(2015) were applied to this study, as they are widely available and commonly used in other research.

Application of PEQI framework to Tsukuba city was involved with a careful review on the PEQI indicators that were utilized in the NACTO, (2015) study. It is an articulation of local pedestrian reality, for example, the narrower widths of sidewalks common to the majority of Japanese urban streets, mixed traffic calming techniques, and public health considerations with regard to aging populations. The PEQI parameters applied in the research were considered locally based on the input of urban planning experts and pedestrian behaviour observations to validate that the index reflects the most critical environmental factors that affect walkability in Tsukuba. This aligns with earlier applications of PEQI for various urban environments where local adaptation is said to be essential for accurate pedestrian environment evaluation (NACTO, 2015; Santos et al., 2022)

3. Methodology

3.1. PEDESTRIAN ENVIRONMENT QUALITY FRAMEWORK

This research employs the Pedestrian Environmental Quality Index (PEQI) parameters, which are used by the National Association of City Transportation Official (2015) in their study of Los Angeles streets, based on the original PEQI framework by the San Francisco Department of Public Health (SFDPH) in 2008. The original PEQI was adopted and specifically tailored to meet the needs of Los Angeles (NACTO, 2015). Given the comparable urban contexts and pedestrian infrastructure needs, the PEQI framework is deemed well-suited for evaluating the quality of walkability in Tsukuba City. Figure indicates the Pedestrian Environment Quality Index (PEQI) Framework utilized in this research.

Pedestrian Environmental Quality Framework

Walkability factor	Indicators
Intersections	
1. Intersection Safety	Crosswalks, ladder crosswalks, pedestrian signs, stop signs, no turn on red signals/sign, curb cuts at pedestrian crossings, signal at intersection, crosswalk scramble, intersection traffic calming features (pavement treatments, median or middle-divider, mini-circles or roundabouts, speed tables, speed humps or speed bumps, bike lane at intersection, partial closures, drains, dips or other unintentional features that slow traffic, curb extensions/bulb-outs, lights set in crosswalk), additional signs
Segments	
2. Vehicular Traffic	Number of lanes, presence of two-way traffic, vehicle speed / posted speed limit, street traffic calming features (street median, speed tables, speed humps or speed bumps, drains, dips or other unintentional features that slow traffic, chicanes, rumble strips, speed limit enforcements)
3. Sidewalks	Width, surface condition, presence of obstructions, presence of curbs, driveway cuts, presence of trees, presence of planters/gardens, presence of public seating, presence of buffers (bike lanes, parallel street parking, grassy or paved margin)
4. Land Use	Storefront/retail use, public art/ historical sites
5. Safety and Aesthetic Qualities	Illegal graffiti, litter, pedestrian scale street lighting, construction sites, abandoned buildings, vacant lots, availability of bike racks on street segment
6. Perceived Walkability	Visual attractiveness, safety, having odors , noise, walkability

Figure 1: Adopted Pedestrian Environment Quality Framework (Source: Compiled by the Author)

3.2. SITE SELECTION

Tsukuba City, situated northeast of the Tokyo metropolitan fringe (Thapa & Murayama, 2009) was selected as the study area due to its high quality of life, steady population growth, and ongoing urban development. With a population density of 851.7/km^2 and an annual growth rate of 1.3% between 2015 and 2020 (citypopulation.de, 2020), the city exemplifies a rapidly evolving urban environment where walkability assessments can provide meaningful insights for maintaining and enhancing urban livability.

The study specifically focuses on the Tsukuba City Core, centered around Tsukuba Center Square, covering approximately 1 km^2 and encompassing major streets (Figure). Within the scope and limitations of this research, this area was selected for its socio-economic importance, high pedestrian activity, accessibility, and diverse land use mix, making it a representative microcosm of Tsukuba's urban environment. The City Core integrates residential, commercial, and mixed-use zones, providing a varied context to evaluate pedestrian infrastructure, street design, and urban form.

Within this core area, 30 intersections and 37 street segments were identified as key components of pedestrian circulation. These selections were based on their functional importance, connection to major roads, and representation of diverse land use and street typologies. Collectively, they capture the spatial and functional variety of Tsukuba's urban fabric, offering a comprehensive framework for assessing the quality of pedestrian environments using PEQI. This strategic selection ensures that the study reflects the city's central pedestrian experience and identifies areas with the greatest potential for walkability improvements.

Figure 2: Case Study Area of Tsukuba City and Major Streets
(Source: Upper right: Thapa, R. B., & Murayama, Y. (2009), Complied by the Author)

3.3. DATA COLLECTION AND ANALYSIS

The research utilizes a combination of direct observations and visual documentation to gather data for the Pedestrian Environment Quality framework, integrating both objective and subjective data. To ensure data reliability, the complete observer method was employed, involving a team of observers, including qualified and subject-matter experts. Observers received thorough theoretical training on the PEQI framework, including definitions of indicators, rating criteria, and procedures for documenting conditions at intersections and street segments.

Figure 3: Numerical Identifier Code for Intersections and Segments (Source: Compiled by the Author)

Two separate forms were used for data collection: one for intersections (10 indicators) and another for street segments (27 indicators), categorized under five walkability factors. Each intersection and street segment was assigned a unique numerical identifier (ID) to ensure accurate tracking of observations and proper assignment of forms (Figure). Observations were conducted during daytime hours (7:00 a.m. to 7:00 p.m.) to capture typical pedestrian activity patterns on both weekdays and weekends. For each indicator, observers recorded conditions through checks, crosses, sketches, photographs, and field notes, ensuring both quantitative and qualitative aspects of the environment were captured.

While analysing the collected data, bellow steps were followed:

a. Data entry: Collected data is entered into Excel sheets using "coder's version" forms, converting qualitative field observation responses (checks, crosses) into numerical data for analysis.

b. Assigning weightage: Each PEQI parameter is assigned a weight based on its relevance within the study context. The weightage values from NACTO(2015) were applied in this study unchanged.

01. Intersection Formula

Step 01

With Traffic Signal: (*Pedestrian Signals + No Turn on Red + Crossing Speed + Scramble*)

No Traffic Signal: (*Stop signs x* 2)

Step 02
Add Above to:

Crosswalks + Ladder crosswalks + Curb cuts + Traffic Calming Features (TCF) count + Additional pedestrian signs)

02. Segment Formula

Number of lanes + Two way + Speed Limit + TCF count + Sidewalk width + Surface + Obstructions + Curb + Curb cuts + Trees + Planters + Seating + Buffers + Retail + Public Art + Graffiti + Litter + Ped − scale Lights + Construction + Abandoned buildings + Bike Racks + Vacant lots + Attractive + Feels safe + Strong odors + Noisy + Walkable)

Figure 4: PEQI Intersection and Street Segment Formulas (Source: Compiled by the Author)

c. Calculation of Existing Conditions: The current pedestrian conditions are calculated by assigning lower weights to poor conditions and higher weights to better conditions. The final PEQI score for an intersection or street segment is obtained by summing the assigned weights according to specific formulas (Figure 4).

d. The scores are then subsequently adjusted to fall within a 0-100 range using the following equation:

$$\mathbf{PEQI} = \frac{(\text{ Unadjusted Score } - \text{Minimum Score})}{(\text{Maximum Score } - \text{Minimum Score})} \times 100\%$$

Figure 5: Adjusted PEQI Score (Source: Compiled by the Author)

e. Next, the current pedestrian environmental quality is identified according to the following color codes.

Table 3: PEQI Score Interpretation

Score	Interpretation	Assigned Colour Code
0 – 20	Environment not suitable for pedestrians	
20 – 40	Poor pedestrian conditions exist	
40 – 60	Basic pedestrian conditions exist	
60 – 80	Reasonable pedestrian conditions exist	
80 - 100	Ideal pedestrian conditions exit	

f. Data Visualization: Finally, the calculated scores for intersections and street segments are visually represented using satellite images. For this research, Google Earth Pro software was utilized to create maps that showcase the quality of the pedestrian environment.

4. Analysis and Findings

4.1. INTERSECTIONS

The analysis of walkability in Tsukuba City, Japan, using the Pedestrian Environmental Quality Index (PEQI) reveals a diverse range of pedestrian conditions across different intersections. The PEQI scores indicate varying levels of pedestrian infrastructure, from poor to ideal conditions (Table).

Table 4: PEQI Summary Table for Intersections

Interpretation	Intersection ID and Final Score (X)
Environment not suitable for pedestrians	I11 (15.63)
Poor pedestrian conditions exist	-
Basic pedestrian conditions exist	I1 (55.46), I5 (55.46), I6 (57.14), I8 (53.78), I12 (45.83), I13 (41.67), I15 (55.46), I16 (52.10), I18 (55.46), I20 (52.10), I24 (55.46)
Reasonable pedestrian conditions exist	12 (65.55), I3 (67.23), I4 (63.87), I7 (65.55), I9 (75.63), I10 (67.23), I14 (67.23), I17 (67.23), I19 (63.87), I21 (63.87), I22 (67.23), I23 (65.55), I25 (65.55), I26 (63.87), I27 (65.55), I28 (63.87), I29 (63.87), I30 (65.55)
Ideal pedestrian conditions exist	-

The most concerning finding is the intersection I11, which scored 15.63 and falls into the "Environment not suitable for pedestrians" category. This score indicates severe deficiencies in pedestrian infrastructure, such as the absence of marked crossings, pedestrian signals, and traffic calming features. These deficiencies make the intersection not only inconvenient but also unsafe for pedestrians. The lack of basic pedestrian amenities at I11 underscores a critical need for infrastructural investments to improve pedestrian safety and convenience.

A significant portion of the intersections, including I1, I5, I6, I8, I12, I13, I15, I16, I18, I20, and I24, fall into the "Basic pedestrian conditions" category. The scores within this category range from 41.67 (I13) to 57.14 (I6). While these intersections provide the necessary pedestrian infrastructure, they still require substantial improvements. The issues in these intersections likely include limited crosswalks and insufficient pedestrian signals, reflecting a need for upgrades to ensure pedestrian safety and convenience. Most of the intersections in Tsukuba City are classified under the "Reasonable pedestrian conditions" category. These include intersections I2, I3, I4, I7, I9, I10, I14, I17, I19, I21, I22, I23, I25, I26, I27, I28, I29, and I30. The scores in this category range from 63.87 (I4, I26, I28, I29) to 75.63 (I9). These intersections demonstrate a satisfactory level, likely featuring properly marked crossings, sufficient crossing time, good pedestrian signals, and better traffic calming features. However, while these intersections meet reasonable standards, there is still room for enhancement to reach optimal pedestrian environmental conditions.

Notably, no intersections in Tsukuba City fall within the "Ideal pedestrian conditions" category. This absence highlights a significant gap in achieving the highest standards of pedestrian infrastructure. It underscores the need for comprehensive improvements across the city to ensure safer, more comfortable, and more accessible environments for pedestrians.

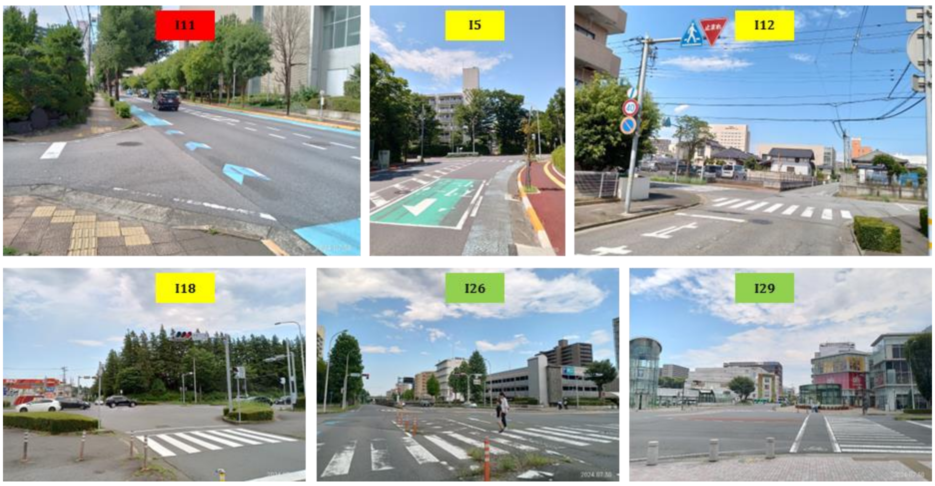

Figure 6: Observed Walkability Conditions in Intersections (Source: Captured by the Author)

4.2. SEGMENTS

The analysis of walkability in Tsukuba City, Japan, using the Pedestrian Environmental Quality Index (PEQI) reveals a diverse range of pedestrian conditions across different segments. The PEQI scores indicate varying levels of pedestrian infrastructure quality, from poor to ideal conditions (Table).

Table 5: PEQI Summary Table for Segments

Interpretation	Segment ID and Final Score (X)
Environment not suitable for pedestrians	-
Poor pedestrian conditions exist	S10 (38.80)
Basic pedestrian conditions exist	S4 (59.62), S5 (57.10), S6 (56.78), S11 (47.32), S21 (55.52), S22 (41.01), S23 (43.85), S24 (48.90), S28 (57.73), S32 (58.36), S33 (54.57), S35 (56.78), S36 (57.10), S37 (57.10)
Reasonable pedestrian conditions exist	S1 (62.15), S2 (71.29), S3 (71.29), S7 (62.78), S8 (65.30), S9 (70.98), S12 (66.56), S13 (60.25), S14 (68.77), S16 (68.14), S17 (67.82), S18 (71.29), S19 (66.56), S20 (65.62), S25 (60.25), S26 (70.03), S27 (65.93), S29 (67.51), S30 (71.29), S31 (68.14), S34 (61.51)
Ideal pedestrian conditions exist	S15 (80.44)

Segment S10, with a score of 38.80, falls into the "Poor pedestrian conditions" category. This low score reflects significant shortcomings in the pedestrian environment, including the absence of sidewalks and curbs, lack of trees or planters, absence of public seating areas, and limited land uses around. These deficiencies contribute to generally uncomfortable pedestrian environmental conditions, resulting in low perceived visual attractiveness, safety, and walkability. The poor conditions in S10 necessitate targeted interventions to address these issues.

Several segments, including S4, S5, S6, S11, S21, S22, S23, S24, S28, S32, S33, S35, S36, and S37, fall into the "Basic pedestrian conditions" category. The scores in this category range from 43.85 (S23) to 59.62 (S4). While these segments provide essential pedestrian infrastructure, they require significant improvements. Common issues in these areas likely include poor sidewalk surface conditions, sidewalk obstructions, lack of trees, absence of seating areas for pedestrians, limited land uses around, absence of bike racks, and lower perceived visual attractiveness and safety. Addressing these factors is crucial to improve the overall pedestrian experience in these segments. The majority of segments, including S1, S2, S3, S7, S8, S9, S12, S13, S14, S16, S17, S18, S19, S20, S25, S26, S27, S29, S30, and S34, are classified under "Reasonable pedestrian conditions." The scores in this category range from 60.25 (S13, S25) to 71.29 (S2, S3, S18, S30). These segments offer satisfactory pedestrian infrastructure, featuring sufficient traffic calming measures, better sidewalk conditions, and continuous lines of trees and planters. However, despite meeting basic standards, there is still significant room for enhancement to elevate these segments to ideal conditions.

Segment S15 stands out as the only one in the "Ideal pedestrian conditions" category, with a score of 80.44. This segment exemplifies an excellent pedestrian environment with well-maintained sidewalks, continuous lines of trees and planters, better land uses around, and importantly, higher perceived attractiveness, safety, and walkability. S15 serves as a model for other areas in Tsukuba City Center, demonstrating the impact of comprehensive pedestrian-friendly design on the overall quality of the pedestrian environment.

Figure 7: Observed Walkability Conditions in Segments (Source: Captured by the Author)

4.3. SUMMARY

Upon analysing the frequency distribution of PEQI scores for intersections, it was noted that the quality of walkability vary across the Tsukuba City (Figure 8), with most intersections providing reasonable conditions (60%), some offering only basic amenities (37%), and a notable few being unsuitable for pedestrians (3%). The lack of intersections in the ideal category points to a considerable potential for urban planning interventions aimed at elevating the pedestrian experience.

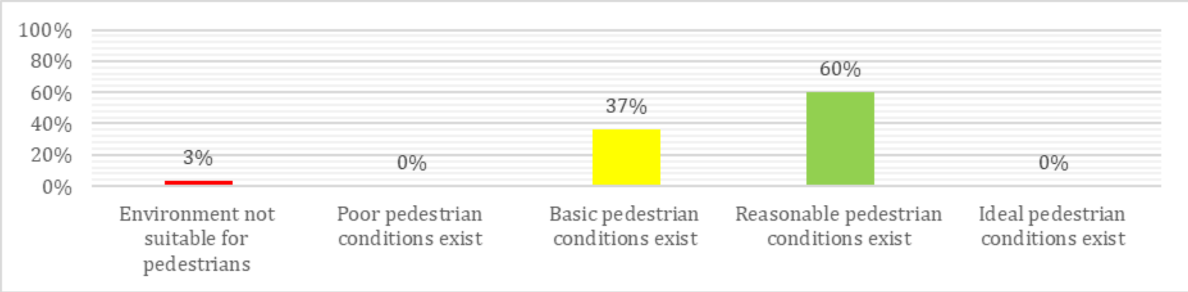

Figure 8: Frequency Distribution of PEQI Scores for Intersections (Source: Compiled by the Author)

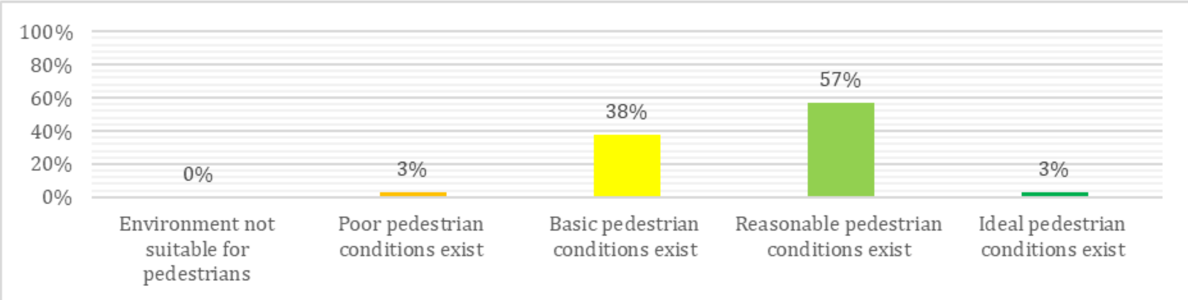

Figure 9: Frequency Distribution of PEQI Scores for Segments (Source: Compiled by the Author)

Upon analysing the frequency distribution of PEQI scores for segments (Figure 9), it was observed a spectrum of walkability conditions across Tsukuba City Centre. While no segments are deemed entirely unsuitable, there is a clear need for improvement in segments with poor (3%) and basic conditions (38%). Most segments offer reasonable conditions (57%), with only one segment achieving an ideal score.

Figure 10: Intersections & Segments PEQI Score Interpretation (Source: Compiled by the Author)

Overall, the intersection and segment analysis using the Pedestrian Environmental Quality Index (PEQI) provides a comprehensive understanding of the existing walkability conditions in Tsukuba City. This analysis highlights significant potential for urban planning interventions to enhance pedestrian infrastructure, aiming to elevate more intersections and segments to ideal standards. Such improvements will ensure a safer, more comfortable, and accessible environment for all pedestrians in Tsukuba City Centre. The analysis, supported by generated satellite images, offers an in-depth overview of the pedestrian environmental quality (Figure 10). By visualizing intersections and segments with PEQI scores, the study effectively identifies areas with high and low walkability, highlighting regions that excel and those requiring improvement. This comprehensive visualization aids in pinpointing specific locations where targeted urban planning efforts can significantly enhance the pedestrian experience in Tsukuba City.

5. Conclusion and Recommendations

In conclusion, the assessment of the quality of walkability in Tsukuba City, Japan through the Pedestrian Environmental Quality Index (PEQI) has provided crucial insights into the city's current pedestrian infrastructure and how it either enhances or diminishes the quality of walkability, essential to ensure urban liveability. The findings highlight significant strengths in certain areas, contributing positively to pedestrian safety and mobility, making parts of Tsukuba City conducive to walking. Additionally, Tsukuba City demonstrates commendable efforts in being disable-friendly, which is a crucial aspect of urban planning that supports inclusivity and accessibility. However, the study also identifies areas that require attention and improvement. The increasing car dependency, despite the city's innovative planning and infrastructure developments, poses a challenge to enhancing walkability. High traffic volumes, inadequate sidewalk widths, and the presence of obstructions on sidewalks are key issues that detract from the pedestrian experience. Another significant finding is that, although trees are present, the shade provided is insufficient, leading to discomfort and potentially affecting the subjective experience of walkability. Based on these findings, the following recommendations are proposed:

- Improve Intersection Safety: Increase crosswalks and pedestrian signals, particularly in high-traffic areas.
- Enhance Pedestrian Infrastructure: Widen sidewalks, enhance surface conditions, remove obstructions, and implement traffic calming measures to improve safety and comfort.
- Enhance Shading: Increase tree planting efforts by carefully selecting species based on their canopy types and strategically placing them to ensure adequate shade along sidewalks.
- Promote Mixed-Use Development: Develop areas that integrate residential, commercial, and recreational spaces to encourage walking.
- Address Safety and Aesthetic Qualities: Improve Street lighting and revitalize abandoned buildings to enhance the sense of security.
- Engage the Community: Subjective experiences are important because they provide insights into how individuals interact with and perceive their environment, ensuring that the planning addresses real needs and enhances overall satisfaction with public spaces.
- Leverage Technology: Use GIS and mobile applications to monitor and assess the quality of walkability, identifying areas for improvement.
- Further Research on Disable-Friendliness: Conduct more in-depth studies on the disable-friendly aspects of Tsukuba City's pedestrian environment.

By implementing these recommendations, Tsukuba City can significantly enhance its quality of walkability, improving public health, environmental sustainability, and overall urban liveability.

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