Spatial Accessibility Measures for Egyptian Cities' Urban Parks Utilizing GIS-Based Methods

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Abstract. Urban parks play a vital role in urban ecosystem by offering resident spaces for recreation and relaxation. These parks are vital for improving urban areas' livability and standard of living. They give both residents and visitors chances for exercise, conversation, and a respite from the hustle and bustle of the city. Urban parks serve as green lung spaces that enhance biodiversity, enhance air quality while reducing the effects of urban heat islands. Assessing the spatial accessibility of urban parks serves as a fundamental starting point in urban planning, enabling the development of strategies that enhance environmental and social justice within urban communities. This research aimed to develop a spatial accessibility GIS model to measure the access of urban parks within the urban context through comparative analysis by Thematic Mapping, Overlay Analysis and Statistical Analysis. The methods used in this study are: Computing the statistical index for the urban parks within an urban context, analysis of spatial proximity to access urban parks and examination of spatial interaction to consider the force of attraction between the origin and destination. The results showed that the statistical index gave data about the parks per person, while the spatial proximity assessed the accessibility variations and finally the spatial interaction approaches offered a unique set of accessibility measures compared to the other previous methods.

Keywords: Urban parks**;** spatial accessibility**;** GIS

1. Introduction

Access to green spaces, like the urban parks, has been associated by increased physical activity (Cohen et al., 2007). Expanding the ability to access of urban parks can help counter the global decline in physical activity and mitigate the growing burden of chronic and obesity illnesses (Booth, Roberts, & Laye, 2011). Moreover, living in close proximity to urban parks has been proposed as a means to enhance residents' quality of life by reducing stress levels and preventing problems of health mentality (Barton & Pretty, 2010).

To ensure improved social and environmental justice and better health outcomes, planners for urban areas and politicians need to prioritize enough access to city parks. However, measuring park accessibility is a complex task due to its multidimensional nature. It involves considerations such as park size, available amenities, and proximity to residents' locations (Zhang, Lu, & Holt, 2011)

Quantifying urban park access has become an area of increasing research interest, with techniques focused on determining park density, the number of parks that can be used within a certain radius or the separation between the nearest park (Zhang et al., 2011). However, these approaches often rely on distance measurements, which can significantly influence the findings (Talen & Anselin, 1998). Existing

researches on park accessibility has limitations in three key areas: using Euclidean distance to determine proximity to residents' homes, representing park destinations using centroids, and ignoring the effects of distance thresholds and transportation modes on measures for accessibility (Halden, Mcguigan, Nisbet, & Mckinnon, 2000).
Urban parks destination choices act as an initial step in developing urban and urban planning strategies (Wang et al., 2021). In Egypt users claimed from inadequate public transportation & relaying on private vehicles, as well as walking distance barriers & poor public transit accessibility (Radwan & Morsi, 2020). Accordingly, limited access to urban parks can negatively impact urban residents' quality of life, as stated by WHO, (2020). The research aimed to develop a spatial accessibility GIS model to measure the access of urban parks within the urban context through comparative analysis by Thematic Mapping, Overlay Analysis and Statistical Analysis.

2. Site description

Madinaty is an expansive housing project situated in the outskirts of Cairo, Egypt. It serves as a self-sufficient community, providing its residents with a diverse array of amenities and resources (TMG, 2024). The initiative for this development was undertaken by Talaat Mostafa Group, a prominent real estate developer in Egypt (TMG, 2024). Which is located in the eastern region of Cairo approximately 30 kilometres away from the heart of the city. The development covers a wide area and benefits from convenient accessibility through well-connected highways and easily accessible public transportation options as shown in (Fig 1) (TMG, 2024). The research targeted two case studies; Central and south parks in Madinaty

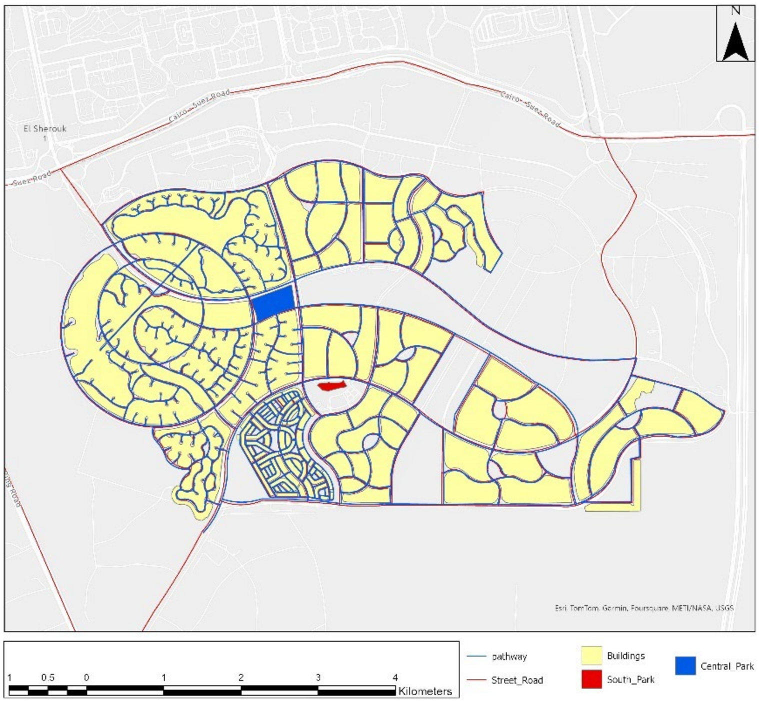

Figure 1 Map for Central & South Parks in Madinaty (By Author, 2024)

3. Parks Brief

Parks serve as green havens accessible to all residents. Urban parks that exceeds 1 square kilometer in size, offer extensive landscapes (Zhao et al., 2023). Duygu et al. (2021) stated that accessible green spaces furnished with services offers recreational needs to the residents in the city. Furthermore, the strategic positioning of these parks at the focal points of the city, as emphasized by Peng et al. (2021), serves dual purposes: preserving ecological balance and meeting the recreational requirements of citizens. Urban parks serve as everyday hubs for social connections and human-nature interactions. They also provide an array of environmental, aesthetic, and recreational benefits that are closely related to the general well-being and well-being of humans (Huai & Van de Voorde, 2022).

4. Accessibility

According to Wang et al. (2021), accessibility to urban parks is the gate where users can get from their residences to these green areas. Neighbourhood parks are crucial in planning to fulfil the users' needs and support the sustainability of urban areas. Park accessibility measures as quantity, size, and the park entrances should be considered in the city planning (Zhang et al., 2011). Spatial accessibility approach is considered one of the most important approaches used by planners to measure urban parks' accessibility. The methods used to measure the spatial accessibility approach are the spatial proximity, the statistical index, and the spatial interaction method (Wang et al., 2021).

The spatial interaction approach utilises the gravity models to calculate the importance of living close to parks. These spatial accessibility methods are essential for assessing different ways to measure parks accessibility. (Wang and others, 2021). The spatial proximity method measures the accessibility of urban parks considering the cost, duration, and travel distance to a park. The statistical index approach accounts number, size, and density within the region of the park (Wang et al., 2021).

4.1. Measuring Accessibility

Urban parks are vital component of the cities. Neighbourhood parks are places where residents utilise on a daily basis and are even more vital for the physical and mental health of the community. (Zhang et al., 2011). Furthermore, parks support cities' ecological and social sustainability. In 2004 (Chiesura) aspects such as the quantity, dimensions, and geographic placement of park gates are considered while planning urban parks (Hartig, Fry, Hagerhall, & Nordh, 2009). The reasons for measuring accessibility are to ensure that park's location is accessible to every resident, to guarantee the best possible spatial distribution and accessibility (Zhang et al., 2011).

As mentioned before accessibility is often measured in terms of cost, time, and distance (Zhang, Sun, Shen, Peng, & Che, 2021). Different modes of transportation like vehicles and pedestrians interacts with the road systems while measuring accessibility. The road network services are vital to be considered while measuring park accessibility. Furthermore, in 2023, Long, Y., Qin, J., and Wu, Y. stated that different facilities must be integrated, with social and economic data to utilize different accessibility techniques.

4.2. Statistical Index Method

A technique known as the statistical index approach uses a park's number, size, or density to quantify parks within a certain geographic area. neighbourhood, postcode, or census tract, for example (Zhang et al., 2011). It's widely used to evaluate park access equity and is practical for gathering data, doing straightforward calculations, and comparing results over time and space (Wang et al., 2021). According to Openshow (1984), it offers a numerical depiction of the locations and features of parks in a certain area. Another tactic is to view every entry point to the park as a final destination (Wang et al., 2021). Nonetheless, a prevalent disadvantage of this methodology is the changeable area unit problem (Openshow, 1984). This problem arises because different spatial scales were used in the analysis to identify the geographic units, which could lead to differences in the geographic measurements or correlations under inquiry. (Wang, 2012).

4.3. Spatial Proximity Method

The spatial proximity method evaluates urban park accessibility via travel time, cost, and distance, as stated by Wang et al. (2021). This means developing either road network or Euclidean measures to calculate distances, while accounting for variables like the amount of parks available within a radius or the closest distance between parks and residences (Liberti et al., 2014). Different methods of transportation as driving, cycling, walking, utilising public transit, is another vital factor to take into account (Wang, 2012).

This method has drawbacks, though. Presuming that individuals always choose the park nearest to them and with the lowest travel expenses may not be correct (Wang et al., 2021). Individuals possess a variety of tastes and distinct requirements, such as looking for specific amenities or picturesque regions in parks (Long et al., 2023).

According to Zhang et al. (2011), addressing these constraints entails taking into account various distance thresholds and transport modalities that residents are prepared to consider. The ideal location to utilise when figuring out how far homes are from parks is another topic of discussion. Even though the centroid of a park is used in many research, bias might be introduced by this simplicity, particularly in bigger parks. Several entrance locations throughout the park's perimeter are an alternative, though in some circumstances this would not be feasible (Wang et al., 2021). Determining accessible entry sites is essential, particularly in cases when access is impeded by natural factors.

4.4. Spatial Interaction Method

According to Zhang et al. (2011), the spatial interaction approach looks at the attractive force between parks (the destination) and residents (the origin). It shows that this force increases with higher demand and larger supply capacity or attractiveness, but it diminishes with increased spatial separation (travel distance or time). Wang et al. (2021) have described the benefits of this methodology over the statistical index method. It addresses the changeable areal unit problem and provides more accurate assessments of population exposure to parks by accounting for attractiveness and service capacity.

Despite its advantages, there are challenges in measuring origin-destination distance and measuring the spatial interaction approach's distance decay effect. Similar to the spatial proximity approach, issues arise in determining distance thresholds, transport modes, and destination choices, according to Long et al. in 2023. The distance decay effect is influenced by a parameter associated with distance, which can vary in different local contexts, as highlighted by Zhang et al. in 2011. Sensitivity to distance also varies across geographic contexts (urban, suburban, rural), with some studies employing a uniform parameter across the entire area, as mentioned by Wang et al. in 2021.

5. Method

The research adopts a technological mixed criteria methodology developed after Wang et Al, (2021), through the following phases: Phase 1: GIS network analysis tool, Phase 2: GIS Overlay technique, and Phase 3: statistical analysis.

- Phase 1: GIS network analysis tool is developed based on the results of the literature review to identify the destination choices, distance threshold by transport modes, and gravity model.
- Phase 2: GIS Overlay technique base om the point scoring for each feature as 1 represents the low accessibility, 2 medium accessibility, 3 high accessibilities.
- Phase 3: statistical analysis to conduct a comparative analysis for the results to show the most suitable methods to measure the park accessibility.

The measurement of OD distances primarily relies on four key factors: the layout of the road network, the available transportation modes, the distance thresholds, and the choices made regarding destinations. In order to capture these factors, for every particular study area the research has used GIS to construct two sets of road network datasets. The road network needed for driving is represented by one dataset, and the road network appropriate for walking is represented by another dataset. This research has created 15 different types of park accessibility measures using the statistical index, spatial proximity, and spatial interaction approaches (2 measures using the statistical index method, 9 measures using the spatial proximity method, and 4 measures using the spatial interaction method) as shown in (Fig 2). Using thematic mapping, overlay analysis, and statistical analysis, the research attempts to analyse and compare the geographical patterns and correlations of these 15 measures. Common operations used in overlay analysis include union, intersection, difference, and proximity analysis. These functions enable the development of new layers or spatial searches that draw attention to certain regions or disclose trends that might not be seen when looking at separate layers separately. In order to showcase the effectiveness of research's approach, which depends on park centroids and edges and its applicability in various geographic contexts, the research has processed to generate 12 different measures of park accessibility. These measures were developed utilizing various spatial proximity measures as well as the method of this study.

5.1. Identifying Destination Choices

In the existing literature, the most common method for finding out where an urban park ends up is usually determined by looking at the park's centroid or the closest edge point. In order to conduct network analysis in GIS, it is essential to extend the road network using a buffer distance that facilitates the connection to the parks. Accordingly, this research identified park destinations using the centroid of a residential area or the nearest edge point of a park to a residential location in order to compare this method with other methods mentioned in the literature. These definitions will be useful for future analysis. Refer to the (Table 1) and (Fig. 2)

5.2. Determining The Distance Threshold Using Transport Modes

In our study of the Madinaty area, the researchers evaluated four specific distances: 500 meters and 1 kilometre for those planning to walk, and 2 kilometres and 3 kilometres for anyone thinking of driving. The World Health Organization has this guideline suggesting that cities should ensure each person has access to at least nine square meters of green space, ideally within a quick 8 to 10-minute walk. This means a walking distance of about 500 to 1000 meters. And for driving, it has been figured out that people might be willing to drive up to five minutes to reach a park. Considering the usual driving speed here in Egypt ranges from 40 to 60 kilometres per hour, a five-minute journey by car would get you about 2 to 3 kilometres away.

5.3. Measuring Urban Park Accessibility

This research produced 15 measures using the spatial interaction, statistical index, and spatial proximity methods (Table 1). Two simple measures were used in this study to calculate the statistical index method: park percentage, which is a percentage of the total area of all parks in a SA1 over its whole size, and park per capita, which is the area of parks in a SA1 per capita. Statistical Area Level 1(SA1) is a geographical categorization that is used to describe small areas for administrative and statistical purposes in many different countries. In the spatial proximity method, the research had 10 measures. The first one, called the closest distance, uses the Closest Route function in Network Analysis in ArcMap to calculate the road network distance between the nearest urban park and a SA1 centroid, which is the population canter of a SA1. Other measures relied on the quantity of access points in a SA1's demand region. The Service Area functions in Network Analysis determined the definition of a SA1's demand area based on the selection of destination choices (park centroids and edges) and distance standards by transport mode (walking distance of 500 m/1 km against driving distance of 2 km/3 km). This study used the spatial interaction approach to calculate the total park accessibility (Ai) of a SA1 (i) to all neighbouring parks within that SA1's demand region using the gravity model as follows.

$$A_i = \sum_{j=1}^{n} S_j \times P_i \Big/ d_{ij}^2$$

The gravity model formula is made up of multiple variables. The capacity for an urban park (j) is indicated by its size (Sj), which is expressed in square meters. Pi is the number of people living in a SA1 (i), which indicates the demand coming from that particular location. The road network-based distance between the centroid of a SA1 (i) and the access points (park centroids and edges) of an urban park (j) is represented by the variable dij. The choice of distance requirements determines how many parks are accessible to the people living in a SA1. To account for this, the research chose specific thresholds for the walking distance of 1 kilometre and the driving distance of 2 kilometres in this gravity model formula.

Table 1 Details of 15 accessibility measures using three different methods. (By Author, 2024)

Methods	**Definition of measures**	**Distance thresholds by transport mode**	**Destination choices**	**Name of measures**	
Statistical index method	Park % refers to the proportion of parks inside a SA1 relative to its overall area. Park per person: the total area of parks in a SA1 per person.	N/A	N/A	SI Park %	60%
		N/A	N/A	SI Park per person	0.002 km/capita
Spatial proximity method	The non-cumulative distance between the nearest park and a SA1 centroid. Cumulative: the total number of access points inside a SA1's demand region.	The nearest distance	Edges	SP- Closest distance	1.8,2.5 KM
		Walking distance 0.5 km	Center	SP-W0.5-cen	Fig. (2)
			Edges	SP-W0.5-edge	Fig. (2)
		Walking distance 1 km	Center	SP-W1-cen	Fig. (2)
			Edges	SP-W1-edge	Fig. (2)
		Driving distance 2 km	Center	SP-D2-cen	Fig. (2)
			Edges	SP-D2-edge	Fig. (2)
		Driving distance 3 km	Center	SP-D3-cen	Fig. (2)
			Edges	SP-D3-edge	Fig. (2)
Spatial interaction method	The gravity model describes the attraction between a park's size (supply) and a SA1's population (demand) over a certain distance.	Driving distance 2 km	Center	Grav-D2-cen	13688888.8
			Edges	Grav-D2-edge	31428571.8
		Walking distance 1 km	Center	Grav-W1-cen	45562130.1
			Edges	Grav-W1-edge	13688888.8

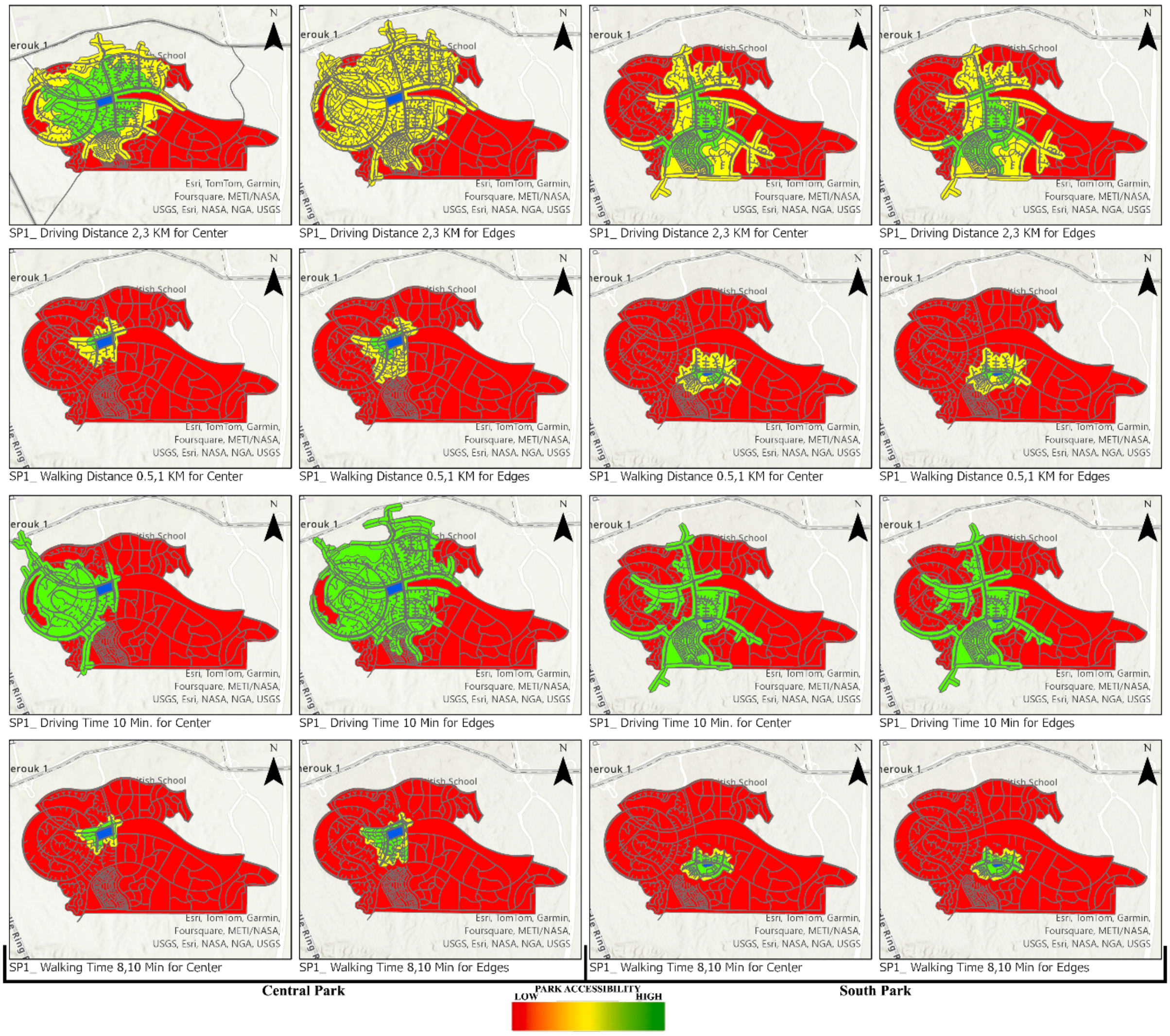

Figure 2 Spatial patterns of 16 park accessibility measures based on park centroids & edges in Central & South Park (By Author, 2024)

6. Results and Discussions

The research analysis of the spatial pattern, overlay, and statistical analysis of the 15 accessibility measures confirms the findings of earlier research by Wang et al. (2021). The statistical index, spatial proximity, and spatial interaction methods produce distinct kinds of accessibility measures that are suitable for various contexts. Based on the statistical index method to look at things like the percentage of parks or parks per person gives us some basic stats, but it might not fully capture what it's really like to get to a park considering how and where people travel. This approach is straightforward and could be more useful for areas where everything's evenly spread out, if there is easy access to data on population and parks.

However, the spatial proximity method adds up a different outcome than the other methods as shown in the previous table. It looks at how accessible parks are without being boxed in by predefined areas like neighbourhoods or cities. In this research, we leaned on this method to consider a bunch of factors, like where people are heading, how they're getting there, the layout of roads and paths, and how far they're willing to travel. By factoring in the actual roads, a much clearer picture will be cleared of how far people need to go to reach a park. This method also suggested using a flexible approach to figure out a park's reach instead of sticking to a one-size-fits-all area. The choice of transportation and how far people are willing to travel play a big role regarding the will to access the parks than just choosing any park to visit. Administrative boundaries often have less of an impact on the method of taking spatial closeness into account utilizing network distances. As long as these areas are connected by a road network, it can be applied to areas with different park sizes and spatial units.

Finally, the spatial interaction method offers a unique set of accessibility measures compared to the other two methods. As this method uses the size of the park as the supply and the population as the demand in the gravity model. Based on the spatial proximity technique, this study defined origin-destination distances in the gravity model while accounting for destination preferences, transport modes, network complexity, and distance thresholds. The park accessibility measures produced by the spatial interaction method may be affected by biases and sizes of the park and population, in contrast to accessibility measures for other facilities. That is due to the ability of an urban park to hold a specific amount of people at a time. However, if the population and park size fluctuate greatly throughout the entire research region, the spatial interaction technique may overestimate or underestimate accessibility measure when the major concern is not the parks' ability to provide services. Therefore, the spatial interaction approach may be more suitable for parks with specific functionalities or those that provide specific facilities where the service capability needs to be taken into account.

The research has conducted a comparative analysis of the statistical results for the spatial patterns of 16 parks' accessibility measures based on park centroids and edges in Central and South Park (Fig 3). By comparing these two spatial units, the research aims to understand how park accessibility measures verities across these different representations. The comparative analysis allowed me to identify any disparities or similarities in park accessibility patterns between park centroids and park edges.

Based on the previous results, using the edge-based method seemed to be more suitable for measuring the Central Park accessibility. Paying attention to the park's edges or boundaries gave a clearer picture of how people can access the park. However, the South Park, it's completely a different story. As it has been found that both the centroid-based method, which focuses on the centre of the park, and the edge-based methods are more privileged as shown in Figure 2. This information can be valuable for urban planners or researchers interested in optimizing park access, identifying underserved areas, or evaluating the effectiveness of park planning and design strategies.

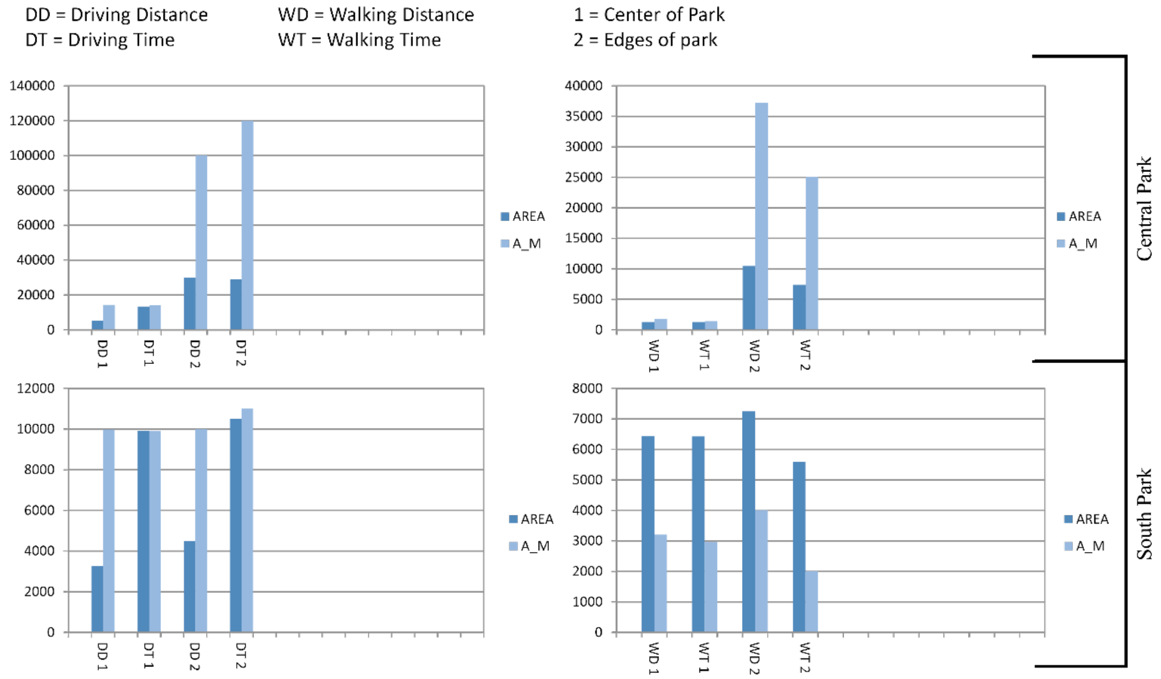

Figure 3 comparative analysis chart of the statistical results for the spatial patterns of 16 park accessibility measures (By Author, 2024)

Table 2 Comparative analysis to identify any disparities or similarities in park accessibility patterns between park centroids and park edges (By Author, 2024)

Principles	Driving distance for center (DD1)	Driving time for center (DT1)	Walking distance for center (WD1)	Walking time for center (WT1)	Driving distance for edges (DD2)	Driving time for edges (DT2)	Walking distance for edges (WD2)	Walking time for edges (WT2)
Central Park					✓	✓	✓	✓
South Park	✓		✓	✓		✓		✓

7. Conclusion

The accessibility research field has greatly benefited from the continual improvement of park accessibility measure and the availability of increasingly precise statistics. This research proposed a method that combined network-based and Centre/Edge-based approaches to accomplish more realistic park accessibility guidelines. The study also compared 15 measures using three GIS-based methods to assess the viability of various accessibility measures. The proposed method has been tested at two research locations in Madinaty, Egypt.

These three methods take into account variables like destination choices, distance thresholds, transport modes, and network complexity. Through the comparison of measurement results, according to this research, different accessibility measures were produced by the statistical index, spatial proximity, and spatial interaction methods that may be suitable in different situations. The results have been found that choice of destination is less effective than the accessibility measurements as much as the distance thresholds and the transport modes. Availability of a specified distance threshold and transport mode that benefits in having more realistic measures regarding the combined network in addition to the centre-edge based methods.

This research presented a pilot study to measure urban park accessibility through different approaches and methods. Started by evaluating the significance of different aspects involved in the measuring process on how accessible the urban parks are, regarding different factors. It builds on previous work done by Santos (2019), Tahmasbi, Haghshenas (2019), and Tomasiello (2020) within the past few years, who have also been examining the benefits of considering these factors can fine-tune the measurements. This research results, which matched with the research conducted by Kaplan, Burg, and Omer (2020), is considered to be a crucial and vital for places that might not have a lot of data to begin with, like developing countries. For instance, the statistical index method could be a lifesaver for measuring accessibility in areas where detailed maps or transport data are hard to be available.

There are certain limitations in this study that can be addressed in the next research:

First, due to the complexity of interaction between behaviour and environment, the boundary of the service area is still up for discussion. The premise behind the geographic zone selection of the service area size is that people's travel and physical activity patterns will be influenced by their proximity to an urban park. It is crucial to emphasize that people must be asked in future surveys how far they would be willing to drive in order to visit an urban park.

Secondly, the analysis in this research only focused on walking and driving private vehicles as modes of transportation; without considering public transportation or combination forms of transportation. Accordingly, many low-income households may not even have the ability to walk or own a private car. Future research can expand to more advanced GIS modelling that takes into account the various forms of transportation that are available (such as ride-sharing and public transportation), the accessibility of urban parks for various population groups, and the function of road network structure.

Thirdly, it is important to recognize that access is a multifaceted and complex concept that encompasses five dimensions: acceptability, cost, availability, accessibility, and accommodation. This research only takes into account one dimension, which is the spatial accessibility determined by the locations of urban parks. The other elements, which represent the social, cultural, and economic aspects, are not taken into account. More park access-related dimensions could be included in future research, such as accessibility (service capacity), cost-effectiveness (price), accommodation (urban park types), and acceptance (individual viewpoint and attitude toward urban parks). Survey techniques and GIS potentials would need to be combined in future research methodology in order to characterize the multidimensional accessibility of urban parks.

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