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A GIS-Based Assessment of Green Space Accessibility: Case Study of Dundee

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ABSTRACT: Recently, it has been proven that access to green spaces provide people with better health conditions and help in enhancing general public health and well-being for urban residents. Therefore, there is a need to assess the quality of green spaces to ensure that they are in good quality in terms of accessibility for example. This paper aims to assess the quality of green spaces in terms of accessibility in the city of Dundee, Scotland based on employing GIS network analysis. The results showed that nearly two thirds of Dundonians have access to 2-20ha green spaces within 300m distance while nearly half of them have access to 20-100ha and 100-500ha green spaces within 2000m and 5000m distance respectively. The findings of this research provide valuable evidence for public policy makers and urban planners in addition to the general public for framing future urban plans in a manner that enhance accessibility to green spaces. The employed methodology in this research can be used in other urban areas within and even beyond Scotland, if the required datasets are available and accessible.

Key words: accessibility; green space; GIS network analysis; urban residents.

Declaration

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Availability of data and material (data are publicly available in Digimap website)

Code availability (ArcGIS is used as software)

1. INTRODUCTION

Green spaces play a vital role in the life of urban residents. It provides economic, environmental, social and cultural benefits (Sister et al. 2008; Moseley et al. 2013). Green space can be defined as a space in an urban area covered by vegetation and it can be publicly or privately accessible (Baycan et al. 2002). Public Health England (2014) defined green space as an area of greenery including public parks, playing fields, streets with plants and others. While Greenspace Scotland (2008) defined green space as “any vegetated land or structure, water or geological feature in an urban area” (Greenspace Scotland 2008). In the context of this paper, green spaces refer to urban green spaces available free of cost for the general public.

Access to good quality green space plays a key role in achieving sustainability and livability. A good quality green space refers to green space that is “fit of purpose” which means that it is accessible, safe, welcoming and performing the intended function (Greenspace Scotland 2008). Accordingly, accessibility is one of all criteria used for assessing green spaces' quality.

Greenspace accessibility can be defined as the ability to reach and access green spaces (Handy 2002). So, it could be determined by the distribution of green spaces and easiness of their access (Vale et al., 2015). While Public Health England (2014) defined it as proximity to a good quality green space and they linked it to the more frequent use of good quality green space. Greenspace Scotland (2008) described accessibility as a term that reflects “how well connected, accessible and inclusive greenspace is to communities” (Greenspace Scotland 2008, p.4).

Researchers have already tackled issues related to the distribution of green spaces across cities and some urban areas (Heynen et al. 2006; Sister et al. 2008, Mueller-ket et al. 2017). GIS techniques and approaches have also been proposed to assess accessibility of green spaces. For example, GIS buffer analysis is employed in several studies (Coutts 2010, 2013; Garg et al. 2018). Although this approach is simple and easy to understand (Coutts et al. 2013), it suffers from the fact that it depends on Euclidian straight line distance that doesn't consider real-world actual walking distance required to travel from one location to another. On the other hand, GIS Network analysis is exploited in most recent studies (Kuta et al. 2014, Kang et al. 2018, Ojiako et al. 2018) as it produces more accurate results. This is due to the fact that it calculates how much distance is required to travel from one place to another based on the network of existing roads and actual walking patterns (Kuta et al. 2014; Ojiako et al. 2018).

Therefore, we can see that on the one hand, there is an acknowledgment of the value of having access to good quality green spaces to enhance human health, well-being and QOL for urban residents. On the other hand, there is a need to assess accessibility to these green spaces to inform decision-makers and urban planners, so barriers and opportunities for enhancing green spaces' accessibility within planning function could be identified.

Accordingly, this paper proposes to assess access to green spaces in the city of Dundee based on employing GIS network analysis tools.

The remainder of this paper is structured as follows. In section 2, we introduce the work related to assessing accessibility to green spaces. Section 3, describes the study area. Section 4 details the steps used to accomplish the assessment process. The produced results are presented in section 5. In section 6, we discuss the conclusions drawn from the results.

2. RELATED WORK

Based on the reviewed literature, five main methodological approaches for measuring accessibility to green spaces are identified and summarized as follows.

A. Counter Approach

Counter approach is also called Opportunity-based measure. This approach measures accessibility to green spaces by counting the number of green spaces in a specific area. This type of measurement has been widely used by planners and services distribution researchers (Lindsey et al. 2001) because of its simplicity in addition to using a small number of variables for measuring access to green spaces. The Counter model suffers from the fact that it defines accessibility based on the number of available green spaces within a specific area, and thus it considers that these green spaces are not accessible for people outside this area, which is not realistic. This approach is modified by considering people who live away from green spaces will access them less, and thus they have a lower level of satisfaction than those who live nearby green spaces (Lindsey et al. 2001).

B. Ratio-Based Measures

This approach depends on finding the proportion between the supply of a facility and the demand for that facility. In green spaces context, it finds the ratio between the area of green spaces and the number of people who live near that green space which indicates the green space resources condition per person (Zhenhuan 2013).

Although this approach provides users with good understanding as it considers both supply and demand, it is not suitable for use in small administrative areas such as postal code zones (Zhenhuan

2013) as it doesn’t consider area crossing behavior. Besides, it suffers from not considering the important variables of time and distance in measuring accessibility.

C. Gravity-Based Measure

This approach mainly focuses on using two factors: the first factor is scale element, for example, areas that have a large population usually have more activities and green spaces than places that have a small population. The second factor is distance, for example, people usually tend to interact with nearby green spaces instead of interacting with regional or district green spaces (Hansen 1959).

The attraction between a residential area and green space is strongly related to the attractiveness of green spaces and the size of the residential population. Also, it is inversely proportional to the distance between residential areas and green space (Zhenhuan 2013).

Although this approach has been used by many researchers to assess accessibility to green spaces (Huang et al. 2017), it suffers from the fact that it is tricky to find the best distance between green spaces and urban residents (Huang et al. 2017).

D. Utility-Based Measures

This approach measures accessibility by assessing the benefits gained from accessing green spaces. In (Lucas et al. 2007), the utility-based approach is used to assess accessibility for different services and facilities, and the produced results are used for measuring social sustainability (Lucas et al. 2007).

This approach assumes that there is a cardinal utility for each alternative people have. And people usually tend to select the choice with the best utility for them. So, this approach is different from others as it depends on individuals. However, it has limitations associated with using complex theories that are difficult to be understood by planners and decision-makers (Zhenhuan 2013).

E. Impedance-Based Measures

This approach tried to overcome limitations identified in the above-mentioned approaches by considering travel distance or travel cost or travel time in measuring accessibility to green space.

The travel distance approach depends on measuring the minimum distance to travel from each residential site to the closest green space access point (Talen and Anselin 1998). This model has the advantage of considering the distance variable which is widely used in recent accessibility studies. Planners usually utilize this variable in creating services areas for different purposes (Zhenhuan 2013). The distance can be measured using different methods such as Euclidean distance, Manhattan distance, and Network distance.

The second impedance-based measure is travel time. This type of measurement is more complex than travel distance as it considers the characteristics of demography, society, and economy for measuring accessibility. For example, travel time between two places may take different values depending on the used traffic mode (walking, biking, or driving a car). Besides, personal characteristics such as age and physical fitness may also affect the required time for traveling.

The third impedance-based measure is the travel cost model which simply measures the average or total cost required for traveling between each origin (centroid of a residential area) and the destination (greenspace access point).

In this paper, impedance-based measures (travel distance) is selected for assessing accessibility to green spaces. This approach is integrated into different GIS tools such as ArcGIS service area analysis (Guo et al. 2019, Kumar et al. 2016), QGIS3 Service Area Analysis using

Openrouteservice (Gandhi 2020) and Java Network Analyzer. ArcGIS service area analysis is employed in this study as it utilizes impedance-based measures for identifying regions that encompass all accessible streets and areas within a specified impedance (distance or time).

3. STUDY AREA

Dundee is Scotland's fourth major city; therefore, it acts as major center for leisure activities, sports, business, retailing and tourism. It is located on the east coast of Scotland at the mouth of River Tay as shown in Figure 1. The population of Dundee in 2011 was 145,570 (Dundee census population 2011). Dundee has a wide diversity of public green spaces covering nearly 1008 ha, which accounts for 16 per cent of the urban area.

As shown in Figure 2, Dundee had a wide variety of public green spaces including parks, amenity open spaces and allotment gardens. Many of these green spaces have multi-use and contribute to the QOL in Dundee by providing an attractive and sustainable urban environment (Dundee Public Open Space Strategy 2008 - 2011).

Fig 1. Study area, Dundee city in Scotland

Fig 2. Distribution of Greenspace Types within Dundee

4. DETAILED STEPS OF THE PROPOSED SYSTEM

Before proceeding to present the details of the methods and techniques used in the proposed system, we introduce – in the context of our work – the terms “Network dataset”, “Service area”, “OD cost matrix” and “Accessible natural greenspace standards”.

Definition 1: Network Dataset:

A Network Dataset (ND) is a dataset that used to model transportation networks. It is usually used to do network analysis and it mainly consists of lines that represent the routes of flow in the network.

ND is triple, ND: = <E, J, T> where:

- E is the set of edges that connect to other elements (J), and they represent the links over which people travel.
- J represents the set of junctions that connect edges and facilitate navigation from one edge to another.
- T is the set of turns that store information that can affect movement between two or more edges.

A Network Datasets is created based on the existing road network in Dundee and it includes pedestrian roads (secondary access road, restricted local access road, minor local road, and local access road). After that, service areas and OD cost matrix are created by network analyst tools in order to assess green space accessibility. Service areas are formally defined as follows.

Definition 2: Service area:

A network service area “is a region that encompasses all accessible streets (that is, streets that are within a specified impedance)” (ESRI 2017b). For example, the 400m service area for a point on a network includes all the streets that can be reached within 400m walking distance from that point. Service areas are created as they help in assessing accessibility.

Service area SA is a sextuple, SA: = <F, L, P, PTB, LB, PNB> where:

- F represents the set of network locations that are used as facilities (green spaces access points) in service area analysis.
- L represents the resultant service areas as linear features and it stores the network edges that can be reached within the given impedance (distance).
- P stores the resultant service area polygons. The Polygons class is empty when a new service area analysis layer is created. It is populated only when the service area analysis layer is solved.
- PTB, LB, PNB represent point barriers, line barriers and polygon barriers respectively. These barriers serve to temporarily restrict, add impedance to, and scale impedance on parts of the network. Adding barriers is optional, it is not required.

Definition 3: Origin Destination Cost Matrix (OD Cost Matrix)

OD cost matrix is used to find the least cost paths in the network from multiple origins to multiple destinations. OD cost matrix analysis layer is a sextuple, OD cost matrix := < O, D, Li, PoB, LiB, and PtB> where:

- represents origins or starting points where paths are generated from them to destinations.
- D represents destinations or end points where paths' ends.
- Li refers to lines that represent the generated paths from origins to destinations.
- PoB, LiB, PtB refer to polygon barrier, line barrier and point barrier respectively. They are used to add and restrict impedance on the network paths. Adding barriers is optional.

Definition 4: Accessible Natural Greenspace Standards (ANGSt)

ANGSt is a standard that determines the minimum distance people need to travel to reach the nearest green space. It was developed in 1990s and it specifies that:

- No one should live more than 300m from their nearest area of green space of at least 2 hectares in size.
- There should be at least one accessible 20-hectares site within 2 kms from residential area.
- There should be one accessible 100-hectares site within 5 kms.

4.1 Data Collection

Assessing green space accessibility entails bringing together several considerations related to the study area including existing green spaces, green spaces access points, existing roads, Dundee boundaries, Dundee data zone boundaries (local neighborhoods) and Dundee census population 2011. These data are publicly available and obtained from three main sources:

- Digimap Ordnance Survey (http://digimap.edina.ac.uk/)
- Scotland's census (http://www.scotlandscensus.gov.uk/)

- Find open data-Data.gov.uk (https://data.gov.uk/)

4.2 Data Preparation and Management

During this step, the collected data are prepared to be used further in network analysis. Preparation and management include organizing the collected data into feature datasets within a file geodatabase. Also, it includes selecting only features that are within Dundee from datasets that cover all Scotland such as green space dataset and data zone boundaries. These features are selected by using ArcGIS clip and selection tools. These tools are used to create new datasets—also referred to as study area or area of interest (AOI)—that contains a geographic subset of the features in another, larger datasets.

4.3 **Network Analysis**

Once the collected data are organized into a file geodatabase, a network dataset is created to do network analysis and establish connectivity between pedestrian roads (secondary access road, restricted local access road, minor local road, and local access road). The created network dataset is built with specifying the following options: setting the connectivity model for the network dataset by letting all streets connect to each other at endpoints; selecting the option that the dataset has no elevation fields. As a result of creating the network dataset, a point feature class containing all junctions that connect pedestrian roads is created with other features classes holding the network dataset attributes.

In order to assess green space accessibility, each requirement of ANGSt is analyzed by executing the following steps:

- OD cost matrix is created to find the least cost (walking distance) between multiple origins (center points of data zones that represent local neighborhoods and residential areas) and multiple destinations (e.g. access points of 2-20ha green spaces for the first requirement of ANGSt).

- The produced result is summarized by summary statistics tool to produce a new table that includes for each origin, the nearest destination (i.e. destination with the minimum walking distance).
- From the produced table in the previous step, select only the origins that have green spaces with specific walking distance (e.g. 300m for the first requirement of ANGSt or 2000m for the second requirement of ANGSt or 5000m for the third requirement of ANGSt).
- To find the number of people living in these data zones and then find accessibility percentages, population data are linked to this table based on database linking property.
- From the produced table in the previous step, the total number of people who have access to green spaces (i.e. people who live in Data Zones that have access to green spaces) according to a specific requirement of ANGSt is found by using statistics tools and then accessibility percentage is found by dividing the number of people who have access to green spaces on Dundee’s total population.

5. RESULTS AND DISCUSSION

This section discusses the produced results from assessing green space accessibility in the city of Dundee. The study area is divided into data zones. Data zone boundaries are designed to provide a geography of local neighborhoods in Scotland. They usually have from 500 to 1000 residents and they are widely used in private and public sectors. Although they are not just residential areas, they still one of the best proxies available for residential areas (Macintyre et al. 2008). Data zones that are within Dundee are only selected for this research. Dundee has 188 data zones and each one has a population ranging from 449 to 1062 except Perth Road-03 data zone has a population of 2901.

GIS network analysis was exploited to assess accessibility to green spaces. Although there are many tools and approaches can be used for doing GIS network analysis such as ArcGIS tools, Service Area Analysis using Openrouteservice (QGIS3), and Java Network Analyzer which provides a collection of graph theory and social network analysis algorithms; ArcGIS tools are selected as they are effective, easy to use and widely used by other researches (Desai et al. 2018; Das et al. 2019). ArcGIS tools are employed based on using ArcGIS software 10.3 (ArcMap 10.3) using a PC with core i5 CPU (2.1 GHz) and (4 GB) RAM. The operating system is Windows 10.

A. Data zones that have access to green spaces according to the first ANGSt

As shown in Figure 3, 108 data zones of 188 data zones have access to 2-20ha green spaces within a 300m walking distance. This means that nearly 57 percent of data zones have access to green spaces according to the first requirement of ANGSt. It is obvious that most of them are located at the center and south of Dundee, while data zones at the east and west of Dundee need to enhance accessibility to 2-20ha green spaces within 300m distance.

The total number of people living in the 108 data zones that have access to green spaces is 88001, and it is calculated by linking the data zones' data with Dundee census data through a database linking property.

Fig 3. Data zones that have access to green spaces according to the first requirement of ANGSt

B. Data zones that have access to green spaces according to the second ANGSt

As shown in Figure 4, 97 data zones have access to 20-100ha green spaces within 2000m walking distance. This means that only 51.5 percent of all data zones have access according to the second requirement of ANGSt, most of them are located in the center of Dundee. However, most data zones at the eastern and southern parts of Dundee don't have such access due to the lack of 20-100ha green spaces in these areas.

The number of Dundonians living in the 97 data zones that have access to 20-100ha green spaces is nearly 74761.

Fig 4. Data zones that have access to green spaces according to the second requirement of ANGSt

C. Data zones that have access to green spaces according to the third ANGSt

Regarding green spaces accessibility according to the third requirement of ANGSt, Figure 5 shows that only 88 data zones of 188 data zones have access to 100-500ha green space within 5000m walking distance. This means that only 46.80 percent of all data zones have access to 100-500 ha green spaces and most of them are located at the west of Dundee. The number of people living in the 88 data zones is nearly 71767.

According to the abovementioned results and as summarized in table 1, nearly two-thirds of people living in Dundee have access to urban green space when considering only the first requirement of ANGSt. While nearly half the population of Dundee have access to urban green space based on considering the second or third requirement of ANGSt. Hence, there is a need to enhance accessibility to green spaces in Dundee by identifying existing barriers and possible opportunities for enhancing it via the planning process.

Fig 5. Data zones that have access to green spaces according to the third requirement of ANGSt

Table 1. Results of measuring accessibility of green spaces based on ANGSt

Requirement / Result	First	Second	Third
No. of people who have access according to the requirement	88001	74761	71767
Number of zones that have access according to the requirement	108	97	88
Percentage of people who have access according to the requirement (%)	59.75	50.76	48.73
Percentage of data zones that have access according to the requirement (%)	57.44	51.59	46.80

6. CONCLUSIONS AND FUTURE WORK

This paper aimed to assess the quality of green spaces in terms of accessibility in the context of Dundee city based on using GIS. Access to green spaces play a key role in enhancing human health conditions as it helps hospital patients to recover quicker; it leads to decrease stress and violence and encourages people to do physical exercises.

ANGSt is selected as a standard for measuring accessibility as it is a powerful tool and used in many previous studies. The proposed approach for assessing accessibility depends on collecting GIS datasets from different resources to be further analyzed using GIS network analysis. The results showed that there are some areas in Dundee that have good access to green spaces according to the requirements of ANGSt. For example, most areas in the center and south of Dundee have access to 2-20ha green spaces within 300m distance. Also, most areas in the north and center of Dundee have access to 20-100ha green spaces within 2000m distance. Regarding access to large green spaces (100-500ha) within 5000m distance, most areas in the western part of Dundee have access to such green spaces, while areas in the eastern part lack such accessibility. So, it is concluded that there are some areas in Dundee need to enhance access to green spaces through the planning process and by identifying current barriers and future opportunities.

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