The GIS-based Research of Measurement on Accessibility of Green Infrastructure – A Case Study in Auckland

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Abstract

Green infrastructure, the most important aspect of improving the quality of life, has been a crucial element of the liveability measurement. With demanding of more liveable urban environment from increasing population in city area, access to green infrastructure in walking distance should be taken into consideration. This article exemplifies the study on accessibility measurement of green infrastructure in central Auckland (New Zealand), using network analysis tool on the basis of GIS, to verify the accessibility levels of green infrastructure. It analyses the overall situation of green infrastructure in two categories and facilities inside each of the category. It draws some conclusions on the city's different levels of accessibility according to the categories and facilities distribution, which provides valuable references and guidance for the future facility improvement in planning strategies.

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1. Introduction

When internationally evaluating cities in terms of liveability, one of the critical aspects needs to be considered is the service level of public facilities such as green infrastructure. According to Marans (2003), reaching liveability goals refers to individual activities and satisfaction. It means that the quality of life is closely related to the provision of natural green areas, the overall quality of ambient environment, and the presence of man-made recreational and cultural resources (Marans, 2003). Among these types of public and open urban areas, the ones providing a greater number of benefits to its users are the ones integrated in the city's green structure, i.e., parks and gardens, which are important elements of green infrastructure (Lopes & Camanho, 2013).

Apart from the benefits of amenities that green infrastructure offers, previous studies have evaluated other functions such as stormwater management, climate adaptation, heat stress reduce, increasing biodiversity, food production, sustainable energy production, clean water and healthy soils, as well as the more anthropocentric functions such as providing shade and shelter in and around towns and cities (Gómez-Baggethun & Barton, 2012). Few researches, however, address the recreational functions of green infrastructure and how the quality of facilities influence the experience of using the green space, which clearly contributes toward the idea of urban 'liveability'.

In Auckland, the city's Auckland Plan strategy promises to promote a better quality of life for all Aucklanders, by encouraging access to more opportunities for recreation, cultural, and leisure activities (Auckland Council, p.36). It ensures that the natural, marine and built environments are responsibly managed, so that citizens will be able to live near the coast and other attractive green and blue edges, within existing neighbourhoods and enjoy them in the future (Auckland Council, p.40). To test whether the social function of green infrastructure has been well considered, research (Haq, 2011) has found that the functionality of green infrastructure is equally influenced by the location and distribution (accessibility) in the whole city. Improving access to green infrastructure, as a result, provides a means for improving equality within urban areas (UNFPA, 2007), and as a consequence, improving 'liveability'. Besides, environmental considerations concerning physical activity and health relate to accessibility, and this accessibility is directly influenced by how recreation areas and facilities are provided and managed (Neuvonen et al., 2007). Thus, using the network analysis method of GIS, this research analysed the actual accessibility levels of green infrastructure in walking distance in Auckland.

2. Accessibility of Green Infrastructure

2.1 The concept of green infrastructure in the context

Publically accessible green infrastructure defined in the literature includes parks and public gardens, green corridors, local natural reserves, urban wetland areas, and beaches, with amenities such as playground, exercise equipment, social gathering sites, bathrooms, refreshment kiosks, and cooking equipment. The idea of green infrastructure was originally influenced by Olmsted's[1] thinking of using connected parks and other open space to enhance the quality of life, and influenced the natural planning and conservation movement of the 19th century city (Pred, 1977). This later led to a refocusing on 'smarter' urban planning policies and approaches for economic growth and environmental protection, which in the United States were referred to as 'smart growth' (Haarhoff et al., 2012, p.13-14). The concept of 'smart growth' accepts that growth and development will continue to occur, but seeks to direct that growth in an intentional, comprehensive way (Preuss & Vemuri, 2004). It comes from rethinking the uncontrolled urban growth due to the rapid urban sprawl and excessive land use.

As with many complex concepts (such as sustainable development), 'Green Infrastructure' has numerous definitions including:

- 'An approach that communities can choose to maintain healthy waters, provide multiple environmental benefits and support sustainable communities.' (The United States Environmental Protection Agency, 2011);
- 'A positive approach for evaluating ecological, social and economic functions which can be used to guide sustainable land use and exploitation, strategies for protecting ecosystem.' (Spitzer, 1999);

[1] Frederick Law Olmsted (April 26, 1822 – August 28, 1903), American landscape architect, was famous for co-designing many well-known urban parks, including Central Park and Prospect Park in New York City.

- 'An entire system to help protect and restore naturally functioning ecosystems by providing a framework for future development that fosters a diversity of ecological, social, and economic benefits. These include enriched habitat and biodiversity; maintenance of natural landscape processes; cleaner air and water; increased recreational opportunities; improved health; and better connection to nature and sense of place.' (Benedict & McMahon, 2002, p.14);
- 'Our nation's natural life support system – an interconnected network of protected land and water that supports native species, maintains natural ecological processes, sustains air and water resources and contributes to the health and quality of life for America's communities and people.' (Benedict & McMahon, 2006; Williamson, 2003, p.4);
- 'Natural and engineered ecological systems which integrate with the built environment to provide the widest possible range of ecological, community and infrastructure services.' (Auckland Unitary Plan, Part 4, p. 40; Boyle et al., 2012, p.5).

According to the definitions above, from the perspective of taking green infrastructure as a sustainable approach or taking green infrastructure as the network of natural system, three aspects are important: ecological, social, and economic benefits. Definition of Benedict and McMahon (2002, p.14; 2006) seems the most widely used in literature (Boyle et al., 2012) as the result of the Green Infrastructure Work Group by the Conservation Fund and USDA Forest Services. In this case, green infrastructure in this research refers to the network of green space and blue space, not only the connected parks and green space systems which has ecological functions to act as a natural system to protect biodiversity and habitats, but also the elements that contribute to urban liveability and its social benefits.

2.2 Accessibility of Green Infrastructure

Accessibility refers to 'the ease with which building, place or facility can be reached by people and/or goods and services' (Cowan & Rogers, 2005). It first appeared from Hansen (1959) as 'the potential of opportunities for interaction'. Other well-known definitions include 'the ease with which any land-use activity can be reached from a location using a particular transport system' (Dalvi & Martin, 1976; Morris et al., 1979), and 'the benefits provided by a transportation/land-use system' (Ben-Akiva & Lerman, 1979). It thus aims to measure the relative opportunity for interaction or contact with a given phenomenon such as a park (Gregory, 1986). From Lynch (1981), accessibility can be viewed as the contribution to the ability of urban residents to have good access to activities, resources, services, information and the like. Pred (1977) specifically relates the quality of life within a city to the accessibility of its inhabitants to nature and extensive recreational open space opportunities.

In this paper, accessibility is a measure of the capability of green infrastructure to provide services and associated benefits. The spatial distribution of public services often reflects the distribution of wealth among citizens (Lotfi & Koohsari, 2009). Lotfi (2009) argued that low income, disabled, elderly and children have the least access to services as these groups are usually unable to use cars. So, from the social perspective, the degree of accessibility to services is a key factor in understanding equity, and the level of access to green infrastructure is an important indicator of the effectiveness of their provision. Thus, the measurement of accessibility in this research is essential for leisure service providers.

3. The Measurement of Accessibility of Green Infrastructure

Network analysis is a useful tool in analysing facility distribution, whereby centres, links, nodes, and impedance are key elements in that analysis (Oh & Jeong, 2007). In this research, the start points are entrances of each green infrastructure; links are pedestrian routes that connect citizens to green infrastructure (highways are excluded from the map as they are not accessible for walking). The walking distances considered in this research refer to three levels: 400 metres (5 minutes' walk, good access); 800 metres (10 minutes' walk, average access); and 1200 metres (15 minutes' walk, poor access) based on the Accessible Natural Greenspace Standards (ANGSt) (Pauleit, Slinn, Handley, & Lindley, 2003). Residents[2] who can be served within the three walking distances are from 2013 Census meshblock dataset.

The general use of this method is in the following steps: (1) sorting out the categories of different types of green infrastructure and its relevant in-

[2] The census usually resident population count of New Zealand is a count of all people who usually live in, and were present in New Zealand on census night, excluding overseas visitors and New Zealand residents temporarily overseas.

formation; (2) setting green infrastructure entrances, road system information, and census data into GIS; (3) calculating the service area and clipping the severed population using network analysis tool; (4) analysing the accessibility levels according to their respective population information in the service areas.

4. Case Study

4.1 Study Area and Data Collection

Auckland city, New Zealand's largest and most populous city, known as the isthmus, is surrounded by oceans and is popular for its natural resources for water sports and recreations close to the seashore. It is one of the few cities in the world to have harbours on two separate major bodies of water.

The study area in central Auckland is approximately 149.75 km^2 and the recorded residents are 413,580 in 2013. There are 102 Area Units and has been divided into five areas based on the geographical location and the road systems: Central Business District (CBD), Eastern Area, Southern Area, Middle Area and Western Area (Fig. 1). The total number of green

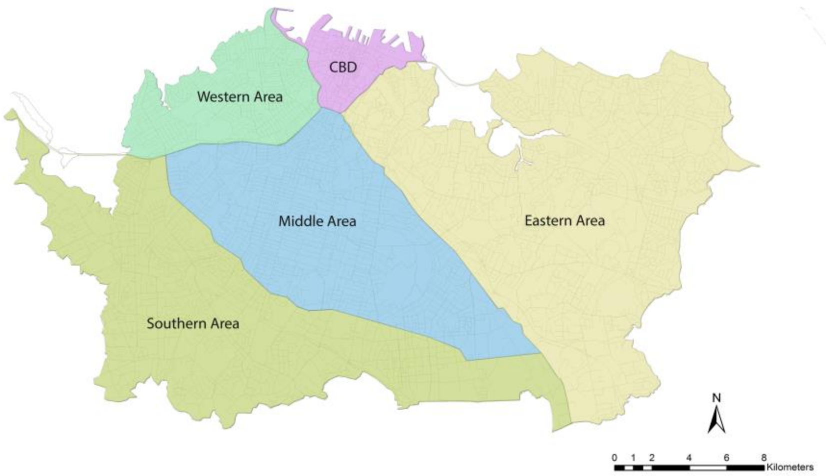

Fig. 1. The study area

infrastructure measured in study area is 338, referring to two categories: Blue space and Green space, each of which consists of four categories in different sizes based on the classification from NZRA (New Zealand Recreation Association) (Table 1): (1) Public Garden (area less than 2000 m^2); (2) Neighbourhood Green Infrastructure (area between 2000 m^2 and 15000 m^2); (3) Sports and Recreation Green Infrastructure (area between 15000 m^2 and 3000 m^2); and (4) Natural Green Infrastructure (area above 30000 m^2). Among these green infrastructure, 55 are blue space, and 283 are green space. Table 2 illustrates the numbers of each category with different sizes. Neighbourhood GI accounts for almost half of the total number (132) of green space, while Natural GI takes most of the number (28) in blue space. On the contrary, Natural GI accounts for 77 in green space and Neighbourhood GI accounts for 16 in blue space as the second largest amount of them.

Table 1. Green infrastructure categories in central Auckland

Types of Green Infrastructure	Area (m^2)	CBD	Western Area	Middle Area	Southern Area	Eastern Area	Total number
Public Garden	<2000	1	14	15	10	7	47
Neighbourhood Green Infrastructure	2000-15000	4	17	33	41	53	148
Sports and Recreation Green Infrastructure	15000-30000	0	1	10	10	17	38
Natural Green Infrastructure	>30000	3	10	13	33	46	105

Table 2. Green infrastructure (blue and green space) in different sizes

Blue Space	Numbers	Green Space	Numbers
Public Garden	7	Public Garden	40
Neighbourhood GI	16	Neigbourhood GI	132
Sports and Recreation GI	4	Sports and Recreation GI	34
Natural GI	28	Natural GI	77

Besides the classification of green infrastructure, other data referred to the research include the map and geographic boundary information of central Auckland from Statistics New Zealand. Road system data can be accessed from Land Information New Zealand (LINZ). The layer used in this research is ‘NZ Primary Road Parcels’. It provides the current road parcel polygons with associated descriptive data and contains three parcel layers (land, hydro and road), which enables easy access to the most common groupings of parcel intents (excluding the non-primary parcels). The layer has a nominal accuracy of 0.1-1m in urban areas and 1-100m in rural areas. As this research considers only the roads and paths for pedestrians, highways that only allow vehicles to access are excluded from the parcel. Meanwhile, the census meshblock[3] and area unit data in 2013 is from Statistics New Zealand as the up-to-date information, which are added in GIS for calculating the population in service areas.

4.2 Facility Conditions in Green Infrastructure

Besides the number of each green infrastructure category, the types of facility and the facility description has been listed in Table 3. These facilities are classified into active facility and passive facility, the former one refers to sports fields, playing ground, fitness equipment, café, historical buildings etc.; and the later one includes chairs, bathrooms, changing rooms, barbeque, drinking fountains, fountains, sculptures, and parking. All these facility conditions are considered in accessibility measurement. Table 4 explains that 142 of all green infrastructure (including blue and green space) have no active facilities installed, 101 of which have no passive facilities, and 81 of which have no single facility inside.

Table 3. Green infrastructure facility categories

Facility Type	Facilities inside Green Infrastructure
Active facilities	Sports fields (football fields, rugby fields, tennis courts, cricket courts, volleyball courts, basketball hoop, boat ramp, scout den, swimming pool, and skate park), children's playing ground, adults' fitness equipment, café, historical buildings
Passive facilities	Chairs, bathrooms, changing rooms, barbeque, drinking fountains, fountains, sculptures, and parking

Table 4. Green infrastructure with facilities

Types of Green Infrastructure	With Active Facilities	With Passive Facilities	With both Active and Passive Facilities	With no Facilities
Public Garden	3	16	16	12
Neighbourhood GI	7	25	67	49
Sports and recrea-	1	4	27	6

[3] A meshblock is the smallest census area used in New Zealand.

tion GI				
Natural GI	7	16	66	16
Total	18	61	176	83

4.3 Comprehensive Evaluation

4.3.1 Overall service area analysis

The population of Auckland central area is 413,580, and the total study area and green infrastrucutre (GI) area are 149.75 km^2 and 16.18 km^2 respectively. The green space per capita is 39 m^2. The central area covers 338 GI (8 in CBD area, 42 in Western area, 71 in Middle area, and 123 in Eastern area). According to the number of population covered in the service area reached in a five minutes' walking distance in Middle and Western area, the figure is over 100 percent (115.54% and 105.70% respectively), which means the service area in this walking distance not only covers all of the population in these areas, but includes a small part of population in other areas who live close to the boundary lines between the two areas. From the result in Table 5, the service ratio in a five minutes' walking distance in Western area and Middle area are among the highest service level. By contrast, the service ratio in Southern asrea is minor, and in CBD and Eastern area is among the lowest level (76.49% and 77.03% respectively). From the service ratio in a ten minutes' walking distance, more people are covered in the service area in all of the areas except Eastern area, which shows that the accessibility to the parks is the best (100%).

The result of the service ratio in a 15 minutes' walking distance indicates that all of the population is covered in this service area, which shows that the residents are able to reach the parks in 15 minutes' walk. The adequate time people take to access to a park is 5-10 minetues, and an acceptable walking distance of human beings in this time period is 0.5-1.0 kilometre. This shows that the accessibility in a 15 minutes' walking distance is reletively low, although all of the population is covered in the service areas within this walking distance.

Table 5. Ovrall service area ratio analysis in five areas in Auckland

Areas	Total population	Served population (5')	Service ratio (%)	Served population (10')	Service ratio (%)	Served population (10')	Service ratio (%)
CBD	31335	23967	76.49	36264	115.73	45969	146.70

Western Area	39492	41745	105.70	51144	129.50	65502	165.86
Middle Area	85074	97446	114.54	125994	148.10	152967	179.80
Southern Area	103803	97902	94.32	122073	117.60	137052	132.03
Eastern Area	153876	118524	77.03	143550	93.29	160608	104.37

Table 6. Service area ratio analysis of blue and green infrastructure

Type of GI	Served population (5')	Service ratio (%)	Served population (10')	Service ratio (%)	Served population (15')	Service ratio (%)
Blue GI	56760	13.72	105729	25.56	152787	36.94
Green GI	346401	83.76	401622	97.11	407136	98.44

The number of Blue and Green GI are 55 and 283 respectively. Compared to Blue GI, the number of Green GI is over five times. The Green GI covers larger service area and serves more population. Totally, the accessibility to Green GI is better than that to Blue GI.

4.3.2 Accessibility levels of green infrastructure in four categories

Based on the classification from NZRA (New Zealand Recreation Association) (Table 1), GI is divided into four categories. Blue GI consists of seven Public Gardens, 16 Neighbourhood GI, four Sports and Recreation GI and 28 National GI. From Table 7, National GI has good accessibility, which covers 10.36% of the whole population in a five minutes' walking distance. While the accessibility of the other three categories are less than that of National GI.

From the Green GI, which consists of 40 Public Gardens, 132 Neighbourhood GI, 34 Sports and Recreation GI and 77 National GI, Neighbourhood GI accounts for larger amount of proportion, approximately twice more than the National GI. In terms of accessibility, the Neighbourhood GI and National GI have better accessibility, covering about half of the population in a five minutes' walking distance. Moreover, almost all of the population was covered when taking 15 minutes' walk.

Table 7. Service area ration analysis of four sized blue and green infrastructure

Type of GI		Served population (5')	Service ratio (%)	Served population (10')	Service ratio (%)	Served population (15')	Service ratio (%)
Blue GI	Public Garden	5007	1.21	10881	2.63	16050	3.88
	Neighbour-hood GI	12393	3.00	29268	7.08	54999	13.30
	Sports and Recreation GI	6501	1.57	13458	3.25	20976	5.07
	Natural GI	42867	10.36	84003	20.31	127182	30.75
Green GI	Public Garden	74082	17.91	146958	35.53	252279	61.00
	Neighbour-hood GI	192720	46.60	317400	76.74	387288	93.64
	Sports and Recreation GI	73815	17.85	155574	37.62	235566	56.96
	Natural GI	219456	53.06	346446	83.77	390726	94.47

4.3.3 Analysis of accessibility of green infrastructure with facilities

From different conditions of facility, green infrastructure with both active and passive facilities provides more opportunities for social activities, social contacts, relax and playing games than that only has active or passive facilities. By contrast, green infrastructure with no facility creates less options for social activitis. From the tables above, National GI, accounting for the largest proportion in Bule GI, serves 8.42% of all population with higher quality of facilities, while Naitonal GI with no facility serves only 0.46%. In terms of Neighourhood GI, the ones with good facility serve 1.97% of all population, while the ones with no facility serve only 0.54%. In Sports and Recreation GI, the service ratio of good facility and none facility is almost the same, with 0.58% and 0.54% respectively. In Public Garden, the service ratio of GI with no facility is similar to that with passive facility.

Table 8. Service area ration analysis of green infrastructure with facilities

Type of GI and facility condition	Served population (5')	Service ratio (%)	Served population (10')	Service ratio (%)	Served population (15')	Service ratio (%)

Blue GI (Public garden)	No facility	2925	0.71	7383	1.79	10611	2.57
	Active facility	1023	0.25	3219	0.78	5808	1.40
	Passive facility	3072	0.74	7143	1.73	12078	2.92
	Active and passive facility	NA	NA	NA	NA	NA	NA
Blue GI (Neigh-bourhood GI)	No facility	2409	0.58	7152	1.73	14406	3.48
	Active facility	NA	NA	NA	NA	NA	NA
	Passive facility	2067	0.50	4698	1.14	9930	2.40
	Active and passive facility	8145	1.97	20220	4.89	36570	8.84
Blue GI (Sports and recrea-tion GI)	No facility	2388	0.58	5970	1.44	9525	2.30
	Active facility	NA	NA	NA	NA	NA	NA
	Passive facility	1419	0.34	2502	0.60	4167	1.01
	Active and passive facility	2244	0.54	4986	1.21	7284	1.76
Blue GI (Natural) GI	No facility	1914	0.46	3597	0.87	4896	1.18
	Active facility	2673	0.65	6306	1.52	12393	3.00
	Passive facility	7845	1.90	16482	3.99	27018	6.53
	Active and passive facility	34827	8.42	71433	17.27	113247	27.38
Green GI (Public garden)	No facility	15708	3.80	42756	10.34	72594	17.55
	Active facility	2940	0.71	8694	2.10	17886	4.32
	Passive facility	30729	7.43	75141	18.17	130173	31.47
	Active and passive facility	32085	7.76	84345	20.39	152361	36.84
Green GI (Neigh-bour-hood GI)	No facility	75822	18.33	153057	37.01	229581	55.51
	Active facility	16674	4.03	41160	9.95	70734	17.10
	Passive facility	43881	10.61	101343	24.50	180630	43.67
	Active and passive facility	107028	25.88	208806	50.49	302007	73.02
Green GI (Sports and recrea-tion)	No facility	7026	1.70	15051	3.64	25944	6.27
	Active facility	1524	0.37	4419	1.07	10092	2.44
	Passive facility	8868	2.14	22497	5.44	41778	10.10
	Active and passive facility	58977	14.26	126756	30.65	198261	47.94
Green GI (Natural GI)	No facility	31881	7.71	61095	14.77	95244	23.03
	Active facility	11493	2.78	28110	6.80	50676	12.25
	Passive facility	34647	8.38	74772	18.08	116670	28.2

	Active and passive facility	166710	40.31	286368	69.24	359742	86.98

4.3.4 Analysis of distribution of green infrastructure with facilities

In general, Middle area offers the largest number of GI with high quality of facilities (with both active and passive facilities) (Table 9). Southern area and Eastern area offer around half amount of GI with high quality facilities. Compared to these areas, CBD offers the least amount of GI with high quality facilities. On the other hand, the figure shows that Eastern area and Southern area have around 1/3 of GI without any facilities. Western area and Middle area indicate that around 1/5 of GI do not have facility. All of the GI in CBD area offers facilities.

Table 9. Distribution of GI with facilties

Areas	Green GI				Blue GI			
	No facility	Active facility	Passive facility	Active & passive facility	No facility	Active facility	Passive facility	Active & passive facility
CBD	0	0	5	2	0	0	0	1
Western	4	3	5	17	5	1	3	4
Middle	11	2	16	42	0	0	0	0
Southern	24	4	8	42	3	2	2	10
Eastern	33	6	16	43	6	0	6	15

5. Conclusions

This study assesses the levels of accessibility to green infrastructure based on different categories and conditions of facilities. The main analyses involved the numbers and percentages of served population. The distribution of high quality of green infrastructure was assessed in terms of facility conditions and service capabilities through GIS network analyses. The following results were obtained: First, service area covered about all of the study area, this is due to the fact that Auckland owns a large amount of green space. The best areas to get access to green infrastructure in five minutes' walk are Western and Middle areas, then Southern area, CBD and Eastern area are the poorest areas for accessible green infrastructure.

Second, the green infrastructure service ratio and facility conditions were found to be particularly useful in assessing the distribution of high quality of green infrastructure.

Third, the relationship among the amount of green infrastructure, the service capability, and the facilities were examined, and the results revealed that almost half of Neighbourhood GI has no facilities.

Finally, insufficient areas of green infrastructure were identified. Eastern area is the place without efficient facilities, which needs to be improved in the future with priority. Also, the GI in Southern area and Western area need to be considered for improvement in facilities. This research is used to improve the quality of GI and maximise its social service function. In the following research, the information of population and income will be considered in the analysis of green infrastructure accessibility in respect of spatial distribution and equity measurement. All of the research is the essential component to guide green space construction and management in different cities.

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