



# Pathways to urban health and well-being: measuring and modelling of community services in a medium size city

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## Abstract

Social and natural capital are fundamental to people's well-being, often within the context of local community. Developing communities and linking people together provide benefits in terms of mental well-being, physical activity and other associated health outcomes. The research presented here was carried out in Christchurch - *Ōtautahi*, New Zealand, a city currently re-building, after a series of devastating earthquakes in 2010 and 2011. Poor mental health has been shown to be a significant post-earthquake problem, and social connection has been postulated as part of a solution. By curating a disparate set of community services, activities and facilities, organised into a Geographic Information Systems (GIS) database, we created i) an accessibility analysis of 11 health and well-being services, ii) a mobility scenario analysis focusing on 4 general well-being services and iii) a location-allocation model focusing on 3 primary health care and welfare loca-

tion optimisation. Our results demonstrate that overall, the majority of neighbourhoods in Christchurch benefit from a high level of accessibility to almost all the services; but with an urban-rural gradient (the further away from the centre, the less services are available, as is expected). The noticeable exception to this trend, is that the more deprived eastern suburbs have poorer accessibility, suggesting social inequity in accessibility. The findings presented here show the potential of optimisation modelling and database curation for urban and community facility planning purposes.

## Introduction

*'Community wellbeing is the combination of social, economic, environmental, cultural, and political conditions identified by individuals and their communities as essential for them to flourish and fulfil their potential.'* (Wiseman and Brasher, 2008).

Social and natural capital have been shown to be fundamental to human well-being (Costanza *et al.*, 1997; Nahapiet and Ghoshal, 1998; Wiseman and Brasher, 2008; Guerry *et al.*, 2015). An important part of personal social capital is an individual's community, which can be families, small groups of people or larger communities, and it has been shown to support physical health and well-being (Helliwell and Putnam, 2004; Vemuri and Costanza, 2006). In Māori culture in New Zealand - *Aotearoa* (NZ), communities have a central place in the organisation of society. Symbolically, communities can be viewed as being held together in a basket (*kete*) with the basket of health (*Te Kete Hauora*) as ultimate goal. In order for the *kete* to be strong it needs many strands of flax (*harakeke*) to come together and be woven tight. Those strands represent the many people, cultures and ethnicities that make up NZ. The strength of the *kete* affects the health and well-being condition of the community (Cram *et al.*, 2006; Harmthworth and Awatere, 2013; Sargisson *et al.*, 2017). These cultural symbols and the central place given to community in NZ society reflect Māori culture, which places a high values on community (Grant, 2017). A strong community needs strong social relations between people in communities, and is a key ingredient of both individual and community well-being (Costanza *et al.*, 2007; Bagnall *et al.*, 2018). Generally, linking people together and re-establishing the concept of a 'city of villages' has been shown to have benefits in terms of well-being, physical activity, and health (Albino *et al.*, 2015; Marans, 2015; Sargisson *et al.*, 2017). In a rebuilding-city context following a post-disaster environment, Christchurch - *Ōtautahi*, a medium size city in NZ, provided the opportunity to explore different

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Key words: Community facilities; accessibility; Health and Well-being; location/allocation modelling; medium size city.

Funding: This research carried out on the WellConnectedNZ (<https://www.wellconnectednz.org/>) project funded by the Health Research Council of NZ and the Ministry of Health. WellConnectedNZ is a project within the Healthier Lives National Science Challenge, one of 11 National Science Challenges designed to find solutions to large, complex issues facing NZers. This research was hosted at the University of Canterbury, Geography department, and the GeoHealth Laboratory of the College of Science.

Conflict of Interest: The Authors declare no potential conflict of interests.

Received for publication: 23 August 2019.  
Accepted for publication: 27 February 2020.

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Licensee PAGEPress, Italy  
Geospatial Health 2020; 15:808  
doi:10.4081/gh.2020.808

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futures, to be innovative and improve the quality of life of its residents as it rebuilt. The 2010/2011 earthquake sequence resulted in 80% of the city centre being demolished due to major structural damage and is still in rebuilding process which will continue well past 2020 (Wood *et al.*, 2016). Christchurch lost a lot of its infrastructure which impacted city life in many ways, with the social impact still ongoing and the long-term cost difficult to estimate (Hogg *et al.*, 2016; Orchiston and Higham, 2016). Since 2011, a number of planning decisions, with consultation and collaboration between stakeholders, researchers, communities and local governments, have taken place to help produce the best reconstruction options (Kingham *et al.*, 2015). The city has started to return to a more normal, less disrupted state, although it remains in a planning and rebuilding process (Marek *et al.*, 2017). It is essential then to provide an overview of the basic primary health care and well-being services supplied to the Christchurch residents and their potential accessibility.

Accessibility can be defined as the ease of reaching destinations and geographical accessibility as the travel impedance between people and a given location (Neutens, 2015). The use of Geographic Information Systems (GIS) to compute geographical accessibility (hereafter just named accessibility) has proven to be an effective and efficient approach (Wiki *et al.*, 2018; McGrail and Humphreys, 2014; Pearce *et al.*, 2006; Bagheri, Benwell, Holt, 2005). Where much work has been done measuring accessibility using GIS (Neutens, 2015), it is still important because of its ongoing importance in land use planning. For example, many GIS accessibility studies are still carried out looking at transportation improvement or service location to public parks (Meng and Malczewski, 2015), urban green spaces (Cetin, 2015), cultural

ecosystem services (Ala-Hulkko *et al.*, 2016) and to primary health care services (Bagheri *et al.*, 2005; McGrail and Humphreys, 2014), and the links between green spaces and human health (Ekkel and de Vries, 2017) have been analysed this way. Likewise, GIS accessibility analysis, such as location-allocation models (L/As) are also frequently used to improve spatial planning of public health (Beheshtifar and Alimoahmadi, 2015; Polo *et al.*, 2015; Zhang *et al.*, 2016). In NZ, the first accessibility analysis using GIS technology to measure community resource locations was done in 2006 (Pearce *et al.*, 2006). This study found clear and expected spatial variation across the country including urban and rural areas. More recently, an accessibility analysis based on GIS has found socio-spatial relationships between food retailers and socio-economic deprivation in urban NZ, highlighting important implications for policy initiatives, health outcomes and sustainable development (Wiki *et al.*, 2018).

Accessibility analysis and optimisation models are widely used to help identify the optimum location of health services, but less frequently for access to local community facilities. However it has the potential to allow a better understanding of how local services can be used by, and within, a community (Wridt, 2010), as well as for the planning of community needs (Masser, 2001; Yeo *et al.*, 2013). In this context, the aim of this paper is to measure and model community accessibility in Christchurch, NZ through the lens of a wide range of services that have been linked to positive health and well-being outcomes. For this purpose, this paper has three objectives: 1). to map and quantify current accessibility; 2). to analyse scenarios by different transport mode; and 3). to use a L/A model to identify locations to optimize accessibility to the primary health care and welfare services.

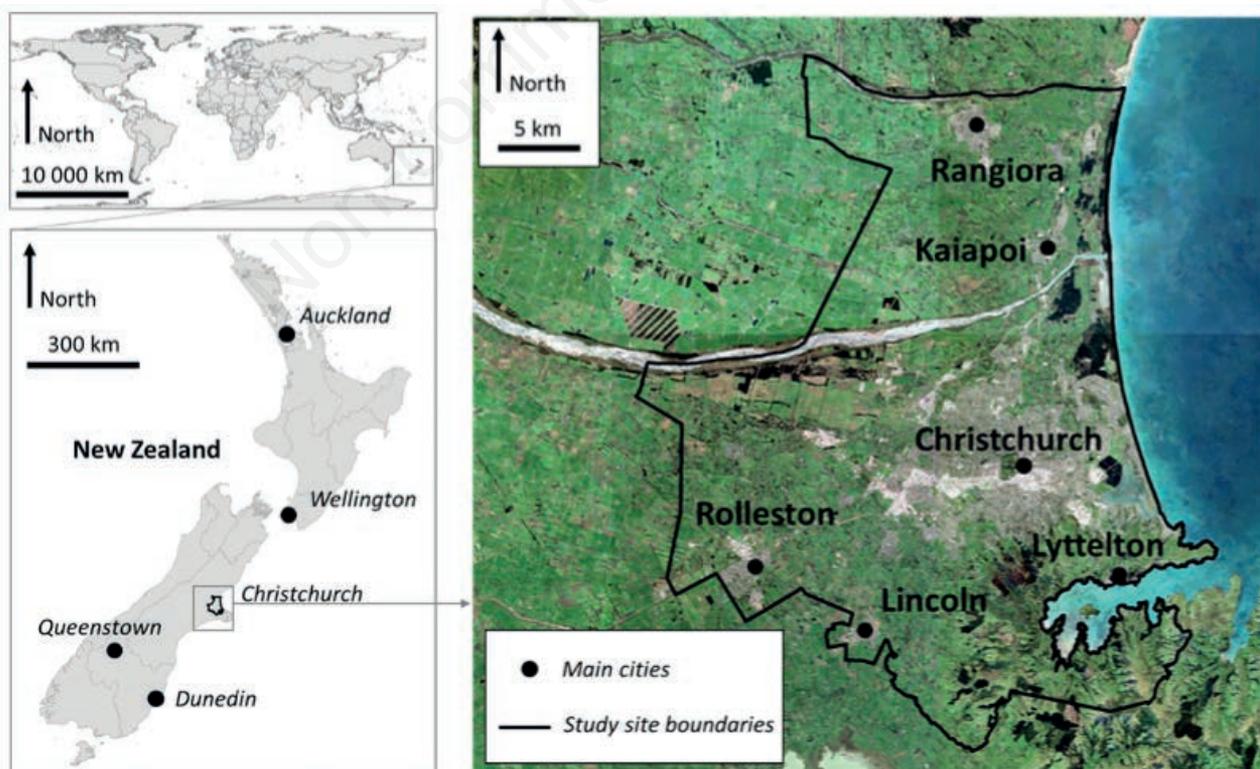


Figure 1. Christchurch - Ōtautahi catchment area.



## Materials and Methods

### Study site

The study included the city of Christchurch and its greater urban catchment area (Figure 1) from Rangiora in the North to Rolleston and Lincoln in the South-west including the port of Lyttelton. Located on the coastal edge of the Canterbury plains, the study area extends 50 km from north to south and 35 km from east to west (approximately 1,200 km<sup>2</sup>) of a largely flat area with hills on the southern boundary. Christchurch is the major urban area in the South Island, the third largest urban area in NZ with 381,800 people in the urban area, and 401,961 people in the whole study area (according to 2013 census). Founded in 1856 as a Garden City, Christchurch is one of the oldest urban settlements in the country. The central city is configured in a regular grid and Christchurch's suburbs are characterised by low property and population densities with large property areas (Kingham *et al.*, 2015).

### GIS Data

Several types of spatial data were collected (Table 1) from: The Ministry of Health (MoH) and Ministry for the Environment

(MfE) in NZ, Community Information Christchurch (CINCH), Open Street Map (OSM), Land Information New Zealand (LINZ), and Statistics New Zealand (STATSNZ). Data were acquired in a 20 km buffer around the Christchurch catchment area (as accessibility analysis does not assume that all the facilities are located inside the catchment area). The data was first projected to the 'NZGD 2000 NZ Transverse Mercator' and subsequently organised in a Geographic Information System (GIS) into four categories: i) *People (source)*: point data of population weighted centroids (PWC) per meshblocks (*i.e.* the smallest geographic unit for which statistical data is collected and processed by STATNZ) (n=3,971 meshblocks, population=401,961) and population density in people/km<sup>2</sup> for each meshblock (see supplementary material S1). ii) *Health and welfare (target)*: location of general practitioners (GPs), hospitals and medical centres, pharmacies, ambulances, and other health services (n=529), as well as welfare places (*i.e.* services designed to promote basic help to people in need) like parenting groups, groups for single mothers, older people and so on (n=109). iii) *Socio-cultural places (target)*: location of community groups (worship, associations, society and clubs, lodges, trusts and trustees, other social groups, *marae*, etc., n=917); cultural groups (art, dance, drama, music, heritage, museums, etc., n=535); educa-

**Table 1. GIS data sources.**

Category	Description	Source	Date	Scale	Number		
People	Population	- Population by Meshblock weighted centroids - Population density	Statistics NZ	2013	National	3,971 (out of 401,961)	
Health and Welfare	Health	- General practitioners	MoH,	2017	National	529	
		- Hospitals and medical centres	OSM	2018	National		
		- Pharmacies	CINCH	2018	Local		
		- Ambulances					
		- Other health services (specialists)					
	Welfare	- Parenting, single mothers, older people, etc.	CINCH	2018	Local	109	
Socio-Cultural	Community	- Worship and ethnic groups	OSM	2018	National	917	
		- Lodges, associations, etc.	LINZ	2018	National		
		- Society and clubs (youth, women, etc.)	CINCH	2018	Local		
		- Trusts and trustees					
		- Other social groups					
		Cultural	- Art, dance, drama, music, etc.	OSM	2018	National	535
			- Heritage and attraction sites	CINCH	2018	Local	
		Education	- Preschools, kindergarten, etc.	OSM	2018	National	792
			- Schools and high-schools	CINCH	2018	Local	
			- University				
	Sport and Recreation	- Athletic, rugby, fitness, martial art, etc.	OSM	2018	National	1,198	
		- Golf courses, parks, playgrounds, etc.	LINZ	2018	National		
			CINCH	2018	Local		
	Food and drink	- Restaurants, supermarkets, fast food, etc.	OSM	2018	National	711	
		- Café, bar, etc.					
Green and blue spaces	Green spaces	- Grasslands	MfE	2018	National	24,555	
		- Forests (natural or planted)	LINZ	2018	National		
		- Native vs exotic vegetation					
		- Scrubs					
		- Shelterbelts					
			- Orchards and vineyards				
		Blue spaces	- Lakes	MfE	2018	National	6,691
			- Wetlands (swamp, mud, pond)	LINZ	2018	National	
			- River				
			- Sand				

Meshblock is the smallest geographic unit for which statistical data is collected and processed by STATNZ. MoH = Ministry of Health, MfE = Ministry for the Environment <https://data.mfe.govt.nz/>, CINCH = Community Information Christchurch <http://www.cinch.org.nz/>, OSM = Open Street Map <http://download.geofabrik.de/australia-oceania/new-zealand.html>, LINZ = Land Information NZ <https://data.linz.govt.nz/>, Statistics NZ <https://datafinder.stats.govt.nz/>.

tion places (preschools, kindergarten schools, colleges, high-schools, university, etc.,  $n=792$ ); and sport and recreation places ( $n=1,198$ ), such as food and drink facilities (restaurants, supermarkets, fast-food, café, bar, etc., ( $n=711$ )). iv) *Green and blue spaces (target)*: represented all the green and blue areas in the study site (grassland, forest, exotic or native vegetation, scrub, lakes, wetlands, rivers, etc.) The population numbers were for green spaces:  $n=24,555$ , and for blue spaces:  $n=6,691$ ). To compute accessibility analysis, a road network data was used (Beere, 2016).

### GIS analysis

Three types of GIS processing were computed: an accessibility analysis of all services ( $n=11$ ); a scenario analysis focusing on four general well-being services; and a L/A modelling focusing on three primary health care and welfare services. All the GIS analyses were computed using ArcGIS 10.4.1. software (ESRI Redlands, CA, USA).

### Accessibility analysis

In the GIS analysis, accessibility was defined as travel time or distance, between demand (e.g., people) and supply (e.g., a service). In other words, accessibility was calculated here as a geographical measure between where people live and where the nearest type of facility is located. The measured accessibility represented the availability of a given service in a given neighbourhood. It did not measure the realised accessibility which refers to other socio-economic factors than only geographical measurements.

The accessibility analysis was computed to determine the required travel time and distance for people to reach a specific location. The travel time/distance was performed between (i) the place of residence (i.e. demand - determined by meshblock weighted centroids) and (ii) the service locations (i.e. supply - facility places determined by socio-environmental data). The objective was to determine the distance and time required for people to access their closest service for each category.

Travel distance (i.e. walking distance) analysis was computed for Euclidian distance in metres between the place of residence and the closest facility of a given type of service (i.e. health, welfare, community, cultural, education, sport and recreation, food and drink, green and blue spaces). Travel time was based on min driving by car. Travel time estimates per services were calculated based on road network data (Beere, 2016). Travel time and distance estimates were computed separately for the following categories: all health and welfare, GPs, public hospitals, pharmacies, welfare, community, cultural, education, sport and recreation, food and drink, green spaces, blue spaces.

### Scenario analysis

The objective of the scenarios was to determine the number of people covered by the current service facilities within a reasonable travel distance or time. We combined the accessibility maps (travel distance and travel time separately) within two scenarios, walking or driving, to four well-being services: health and welfare, community places, cultural places, sport and recreation activities. The two scenarios were:

- Walking Scenario, which was calculate as the walking distance (in metres) between the place of residence and the chosen ser-

vice category. Walking speed was estimated at around 4.5 km/h (Chen *et al.*, 1997; Terrier and Reynard, 2015). The chosen thresholds were i) less than 10 min walking for a good level of accessibility (i.e. less than 750 m that represented a reasonable walking threshold; Smoyer-Tomic *et al.*, 2004), ii) between 10 to 20 min walking for a medium level of accessibility (between 750 to 1,500 m), iii) more than 20 min walking was considered as a low level of accessibility (>1,500 metres; Tsou *et al.*, 2005); and

- Driving Scenario, which was calculated as the driving time (in min) between place of residence and the chosen service category. The estimated driving speed was the maximum speed limit, varying according to road configurations (Beere, 2016). The chosen thresholds were i) <5 min driving for a good level of accessibility, ii) 5-10 min driving for a medium level of accessibility, iii) >10 min driving for a low level of accessibility for a medium size city in the NZ context (Langford and Higgs, 2006; Pearce *et al.*, 2006; Neutens, 2015).

A synthesis analysis was computed for the two scenarios. The objective was to map the areas with high, medium or low levels of accessibility for all services. Firstly, we mapped separately the accessibility level for the four selected services and for the two scenarios using the time and distance maps and following the scenario thresholds. Secondly, we merged together the four service maps for each scenario to produce a synthetic map of accessibility level to all services for the Christchurch study area.

### A location-allocation model

A L/A model was computed to create scenarios that increase accessibility to primary health care and welfare services. The objective of the model was to determine the optimal location of a given service according to a given demand. This type of model allows to optimize travel distance or time between people (demand) and services (facility locations), but it does not take into account the number of people that are likely to receive by an existing facility. Consequently, the optimal number could not provide sufficient service for the whole population.

The objective of this model was to define, given demand, where would be the best facility locations in order to increase accessibility. The two scenarios (walking and driving) were tested in this model. Most of the L/A models in the literature defined <10 min driving as an acceptable driving time to reach a facility (Langford and Higgs, 2006; Pearce *et al.*, 2006). Therefore, we kept this threshold to compute the driving scenario. Under the driving scenario, we analysed how the changes required would affect pedestrians.

The L/A model we developed was based on: i) *Demand*: people place of residence (determined by meshblock weighted centroids); ii) *Services*: all the health and welfare existing services as a bundle of available places for primary health care service locations; and iii) *Transport*: car driving using a GIS road network according to Beere (2016).

The model was computed for three different services (GPs, pharmacies, welfare places) and following three different scenarios: i) minimizing the number of facilities; ii) maximizing the attendance and so increase the current accessibility; and iii) maximizing the coverage of a given type of service.



## Results

### Accessibility analysis

The accessibility analysis allowed computation and mapping of the travel time and distance from a place of residence to the closest service facility. Summary statistics are presented (Table 2). Figures 2 and 3 display travel distance and time accessibility maps presented in quintiles (referring to Table 2) for the 9 main services (Figures 2 and 3 exclude green and blue spaces presented in supplementary material S2). For the whole catchment area, the mean and median travel distances for most of the services (except public hospitals and welfare) were less than 1 km (Table 2). As there are only three public hospitals in the study area, the public hospital accessibility cannot be compared with other type of services. For health and welfare services, the GPs and pharmacies facilities are well distributed across the study area and the mean distance is just less than 1 km, and the mean driving time is less than 2.5 min (Table 2). Welfare facilities are sparsely and unevenly spatially distributed. There are more than a hundred welfare facilities, but the mean distance between people and the nearest facility is more than 1.6 km (Table 2). The socio-cultural places are easily reachable with a mean distance around 500 m, so they can be reached easily by walking, otherwise the mean driving time is very small, around 1 to <2 min (Table 2). Green and blue spaces are well distributed and easily accessible too (means are 204 m and 441 m, respectively (Table 2), which means that these places are spread all over the city (see supplementary material S2). This can be considered a good point given that these elements had proven to be as positive

impact in mental health and well-being for the whole population regardless of age or condition (Finlay *et al.*, 2015; Gascon *et al.*, 2015; Thompson and Aspinall, 2011).

The different services seem to be well distributed spatially (Figures 2 and 3). Although Christchurch City is well covered by a wide range of services than peripheral areas, there is no evident city centre. Maps display a multi-centred city offering a well spread and wide range of facilities for all the type of services across a large number of neighbourhoods. This pattern is particularly evident in the travel distance maps (Figure 2). The travel driving-time pattern is slightly different (Figure 3). The accessibility is more clustered around the facilities especially for the medium to low accessibility classes. For population density (Supplementary material S1), the supply of services seemed to serve most areas well, with the exception of the eastern suburbs looking less well served (Figure 2).

### Scenario analysis

The scenario objective was to determine the number of people covered by the current service facilities within a reasonable travel distance or time. As a reminder, the walking scenario defined an average speed of 4.5 km/h with thresholds being less than 10 min, 10-20 min and >20 min corresponding to <750 m, 750-1,500 m, and >1,500 m. These selected thresholds generally match up globally to the second and fourth quintile of the travel distance analysis (Table 2). The driving scenario time thresholds used are <5 min, 5-10 min, and >10 min, which correspond to the same quintiles of the travel time analysis (Table 2).

The number and percentage of people covered by facilities within the chosen thresholds for the walking and driving scenarios

**Table 2. Summary statistics of accessibility analysis.**

Category	Median	Mean	SD	Q1	Q2	Q3	Q4	Q5	Maximum
All health and welfare	416.9 <i>1.24</i>	647.4 <i>1.57</i>	840.3 <i>1.35</i>	4.4 <i>0</i>	207 <i>0.64</i>	341 <i>1.03</i>	508 <i>1.5</i>	789.5 <i>2.14</i>	8,231.5 <i>11.32</i>
GPs	683.7 <i>1.88</i>	970.3 <i>2.28</i>	1,051.5 <i>1.72</i>	22.8 <i>0.02</i>	369.7 <i>1.07</i>	575.8 <i>1.6</i>	815.4 <i>2.17</i>	1270 <i>3.16</i>	12,331.5 <i>14.1</i>
Public hospitals	3925.7 <i>8.8</i>	5,502.5 <i>9.9</i>	4980 <i>5.57</i>	64.2 <i>0.49</i>	1977 <i>5.8</i>	3339 <i>7.9</i>	4666 <i>9.74</i>	7235 <i>13.1</i>	26,463.4 <i>34.6</i>
Pharmacies	690.1 <i>1.89</i>	994.4 <i>2.4</i>	1,092.6 <i>2.33</i>	9 <i>0.001</i>	385.3 <i>1.1</i>	584.3 <i>1.63</i>	803 <i>2.2</i>	1233 <i>3.15</i>	11,336.1 <i>34.55</i>
Welfare	909.3 <i>2.45</i>	1,677.6 <i>3.5</i>	1,948.7 <i>3.5</i>	4.4 <i>0.001</i>	406 <i>1.22</i>	715.7 <i>1.98</i>	1,187.6 <i>3</i>	2452.8 <i>4.9</i>	11,881.4 <i>34.25</i>
Community	337.1 <i>1.1</i>	540.5 <i>1.4</i>	770.4 <i>1.29</i>	3.3 <i>0</i>	165.3 <i>0.53</i>	278 <i>0.88</i>	410.3 <i>1.28</i>	657 <i>1.95</i>	9439 <i>13.18</i>
Cultural	488.5 <i>1.44</i>	686.6 <i>1.76</i>	724 <i>1.38</i>	13.8 <i>0</i>	237.8 <i>0.73</i>	395.8 <i>1.2</i>	586.1 <i>1.7</i>	920.5 <i>2.5</i>	7,585.2 <i>11.44</i>
Education	305 <i>0.9</i>	454.5 <i>1.22</i>	549.1 <i>1.02</i>	5.5 <i>0</i>	165 <i>0.51</i>	253 <i>0.81</i>	360 <i>1.15</i>	554.8 <i>1.7</i>	5,906.6 <i>9</i>
Sport and recreation	316.8 <i>1</i>	422.9 <i>1.14</i>	432.3 <i>0.81</i>	3.3 <i>0</i>	169.2 <i>0.5</i>	262.4 <i>0.83</i>	377.4 <i>1.16</i>	553.5 <i>1.65</i>	4,787.1 <i>9.32</i>
Food and drink	517.4 <i>1.42</i>	732.8 <i>1.85</i>	580.4 <i>1.6</i>	9.8 <i>0</i>	249.2 <i>0.74</i>	418.4 <i>1.18</i>	628.5 <i>1.7</i>	966.1 <i>2.6</i>	8,442.5 <i>15.85</i>
Green spaces	168.7 <i>0.85</i>	203.9 <i>0.89</i>	166.1 <i>0.54</i>	0 <i>0</i>	73.1 <i>0.4</i>	134.5 <i>0.7</i>	206 <i>1</i>	312.2 <i>1.33</i>	1,586.6 <i>5.6</i>
Blue spaces	355 <i>2.15</i>	441 <i>2.25</i>	347.1 <i>1.24</i>	0 <i>0</i>	145.1 <i>1.12</i>	274 <i>1.83</i>	441.9 <i>2.5</i>	695.3 <i>3.31</i>	2,320.8 <i>6.7</i>

SD= Standard deviation; Walking distance (m); Travel time by car (*min*).

are presented in Table 3. The results confirm what was already shown by the accessibility analysis that the supply of services seems to serve most communities well. Almost 97% of the Christchurch catchment population are covered by a health or welfare facility within 5 min driving time (Table 3), with 94.6% and 98.7% of the population living less than 5 or 10 min driving time from the nearest GP, 93.4% and 98.3% living less than 5 or 10 min from the nearest pharmacy, and 80.1% and 94.5% living less than

5 or 10 min from the nearest welfare facility. The community, cultural, educational, sport, recreation, food and drink places are also really well distributed as 95% of the population are less than 5 min away if driving and more than 99% less than 10 min (Table 3).

These services are less accessible for people relying on walking, with 80% living <10 min walk from a health or welfare facility, and 92.4% <20 min (Table 3). Only 56.6% of people live less than a 10 min walk from their nearest GP, but it increases to 86.6%

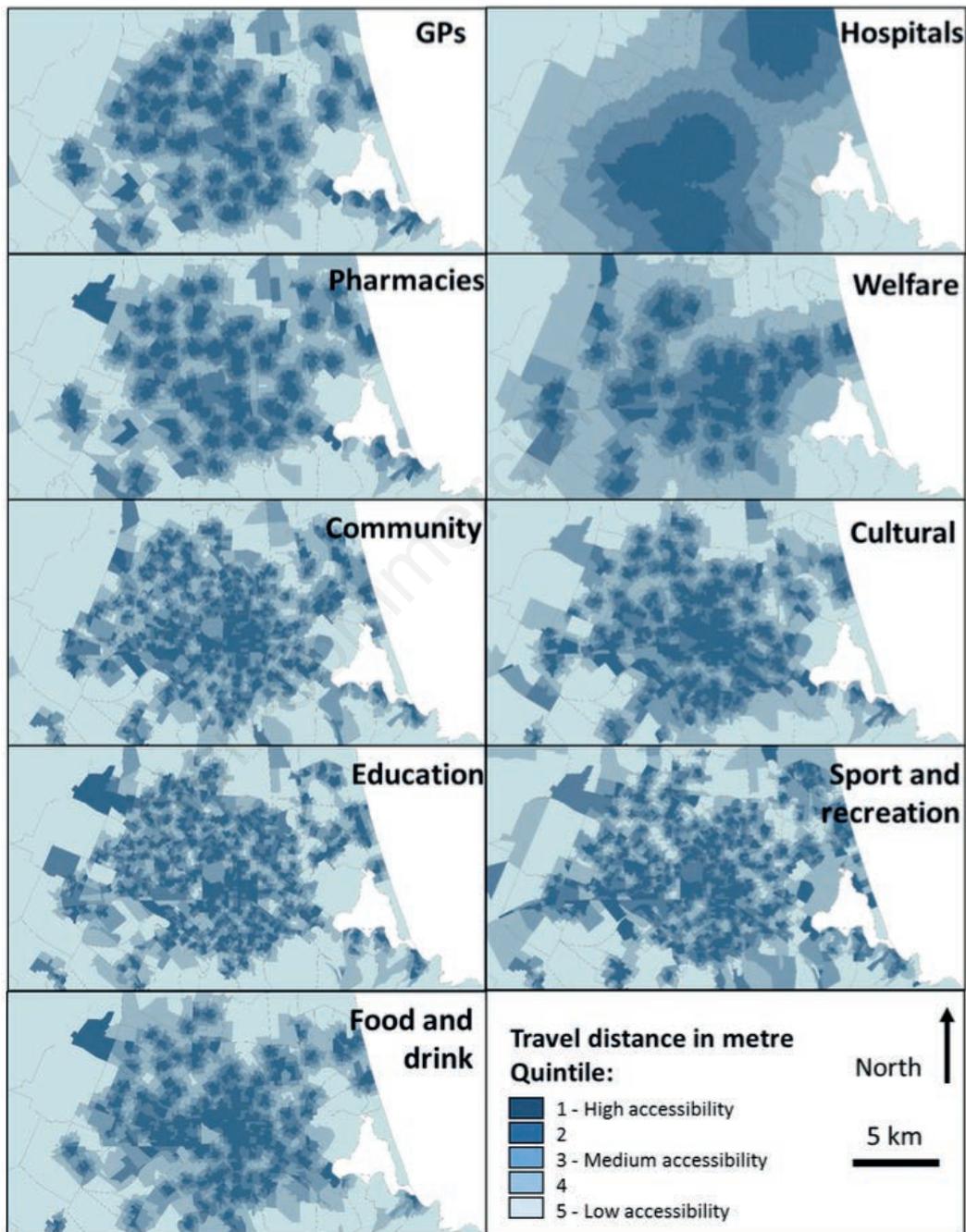


Figure 2. Travel distance maps from the place of residency (population weighted centroid by meshblocks) to the main facility, by service type. Zoom in Christchurch - Ōtautahi city.

of people living less than a 20 min walk away. It is the same pattern for the pharmacy coverage, with only 45.5% people living less than a 10 min walk from their nearest pharmacy, increasing to 85.3% for less than a 20 min walk. The percentages are also lower for welfare facilities with only 40.2% people <10 min and 68.9% people <20 min away. However, the community, cultural, educational, sport, recreation, food and drink places are better distributed with more than 90% of the population <20 min and 70% <10 minute away (Table 3).

This scenario analysis is useful to better consider how well people can access different types of services. As socio-cultural places have been shown to play a key role in well-being, it is important to highlight the good coverage of these services all around the Christchurch area.

The level of accessibility to four categories of well-being service: health and welfare, community, cultural, sport and recreation; is shown (Figure 4). The two maps display the walking and driving scenarios separately. Results show that i) Christchurch city is well

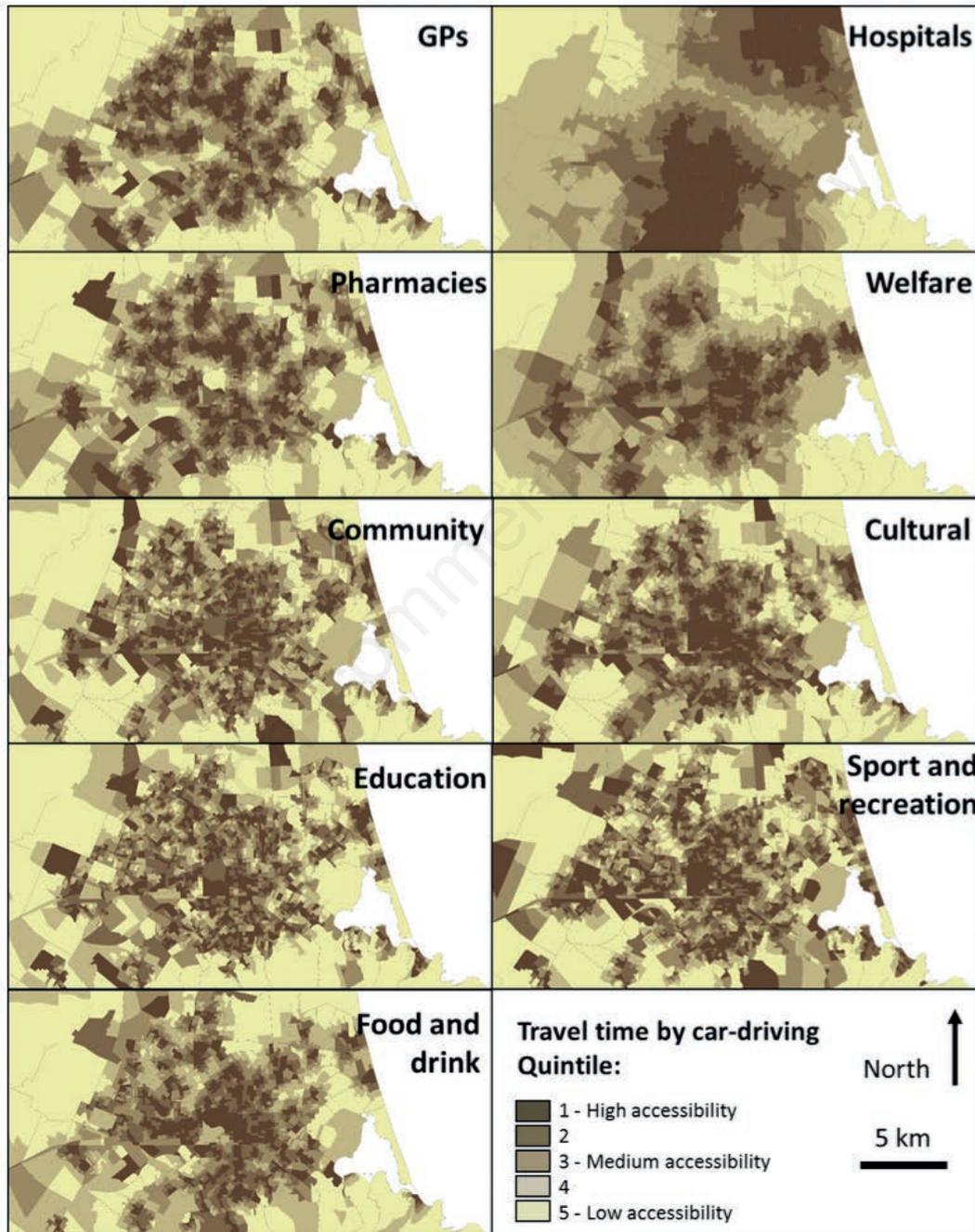


Figure 3. Travel driving-time maps from the place of residency (population weighted centroid by meshblocks) to the main facility, by service type. Zoom in Christchurch - Otautahi city.

covered in terms of access to well-being services, ii) as expected, the further away from the centre, the less services are accessible, iii) even the small satellite urban areas (Rangiora, Kaiapoi, Woodend, West Melton, Rolleston, Lincoln, Lyttleton) have reasonable service accessibility. However the eastern suburbs are sparsely served (similar to the accessibility maps in Figures 2 and 3) with the socio-economic multiple deprived (Salmond *et al.* 1998; Exeter *et al.* 2017).

### A location-allocation model optimises inhabitants' accessibility

#### General Practitioners

If we want to i) minimize the number of facilities and keep the same coverage (*i.e.* the same percentage of people that can reach the nearest GP in <10 min driving), only 18 of the 114 centres are technically allowed. This result shows that 18 centroids points can geographically cover the same number of living places than the 114 existing. But we can think about relocating some places to ii) maximize the attendance and so increase the current accessibility. With the same number of facilities (114), keeping 26 of the current places and relocating 88 in existing health and welfare facility places, would increase accessibility to 99.82% of people (401,235) living within 10 min driving time. This scenario would increase the accessibility up to 68% and 90.2% of people to less than 10- and 20-min walking, respectively (*i.e.* +11.4% and +3.6% respectively). If we want to iii) maximize the coverage of GP facilities, we

will need to add nine places (from existing health and welfare or community facilities) to have 100% of Christchurch inhabitants within 10 min driving time. This scenario would not change anything for the walking people. It is explained by the rurality of the nine new places, far from living places but easily accessible by car.

#### Pharmacies

If we want to i) minimize the number of facilities and keep the same coverage, only 16 of the 125 centres would remain. But if we relocate some places to ii) maximize the attendance and increase the current accessibility, with keeping 6 of the current places and relocate 119 in existing health and welfare places, this would increase accessibility to 99.82% of people (401,235) in less than 10 min driving. This scenario would increase the accessibility up to 69.5% and to 90.4% of people living within a 10 and 20 min walk away respectively (*i.e.* +24% and +5.1% respectively). Finally, if we want to iii) maximize the coverage of pharmacy facilities, we will need to add 10 places (from existing health and welfare or community facilities) to have 100% of Christchurch inhabitants within 10 min driving. This scenario would allow an increase of accessibility up to 54.2% and up to 85.6% of people by walking less than 10 and 20 min respectively (*i.e.* +8.7% and +0.3% respectively).

#### Welfare places

If we want to i) minimize the number of facilities and keep the same coverage, only 14 of the 109 centres would remain. But if we

**Table 3. Amount of people covered by current facilities.**

Service category	Walking distance			Driving time		
	<10 min	10-20 min	>20min	<5 min	5-10 min	>10 min
All health and welfare	316,296 <i>78.7</i>	54,981 <i>13.7</i>	30,681 <i>7.6</i>	389,181 <i>96.8</i>	12,054 <i>3</i>	723 <i>0.2</i>
GPs	227,526 <i>56.6</i>	120,639 <i>30</i>	53,793 <i>13.4</i>	380,190 <i>94.6</i>	16,644 <i>4.1</i>	5,124 <i>1.3</i>
Public hospitals	8,250 <i>2.1</i>	29,898 <i>7.4</i>	363,810 <i>90.5</i>	53,520 <i>13.3</i>	191,289 <i>47.6</i>	157,149 <i>39.1</i>
Pharmacies	182,844 <i>45.5</i>	160,050 <i>39.8</i>	59,064 <i>14.7</i>	375,585 <i>93.4</i>	19,746 <i>4.9</i>	6,627 <i>1.6</i>
Welfare	161,739 <i>40.2</i>	115,392 <i>28.7</i>	124,827 <i>31.1</i>	321,993 <i>80.1</i>	57,780 <i>14.4</i>	22,185 <i>5.5</i>
Community	339,447 <i>84.4</i>	38,817 <i>9.7</i>	23,694 <i>5.9</i>	391,722 <i>97.5</i>	8,622 <i>2.1</i>	1,614 <i>0.4</i>
Cultural	284,538 <i>70.8</i>	78,396 <i>19.5</i>	39,024 <i>9.7</i>	387,255 <i>96.3</i>	14,295 <i>3.6</i>	408 <i>0.1</i>
Education	356,934 <i>88.8</i>	25,731 <i>6.4</i>	19,293 <i>4.8</i>	396,525 <i>98.6</i>	5,433 <i>1.4</i>	0 <i>0</i>
Sport and recreation	363,894 <i>90.5</i>	25,044 <i>6.2</i>	13,020 <i>3.2</i>	400,293 <i>99.6</i>	1,665 <i>0.4</i>	0 <i>0</i>
Food and drink	276,171 <i>68.7</i>	86,466 <i>21.5</i>	39,321 <i>9.8</i>	384,207 <i>95.6</i>	15,738 <i>3.9</i>	2,013 <i>0.5</i>
Green spaces	397,239 <i>98.8</i>	4719 <i>1.2</i>	0 <i>0</i>	401,958 <i>100</i>	0 <i>0</i>	0 <i>0</i>
Blue spaces	326,025 <i>81.1</i>	70,689 <i>17.6</i>	5,244 <i>1.3</i>	392,655 <i>97.7</i>	9,303 <i>2.3</i>	0 <i>0</i>

Non-italics = numbers of people; Italics = expressed as percentage

relocate some places to ii) maximize the attendance and increase the current accessibility, 19 of the current places would remain and 100 existing health and welfare facility places would be relocated, increase accessibility to 99.82% of people (401,235). This scenario would increase the accessibility up to 66.5% and to 90.1% of people walking less than 10 and 20 min respectively (*i.e.* +26.3% and +21.2% respectively). Finally, if we want to iii) maximize the cov-

erage of welfare facilities, we will need to add 14 places (from existing health and welfare or community facilities) to have 100% of Christchurch inhabitants within 10 min driving. This scenario would allow to increase the accessibility up to 43% and up to 73.8% of people walking less than 10 and 20 min respectively (*i.e.* +2.8% and +4.9% respectively).

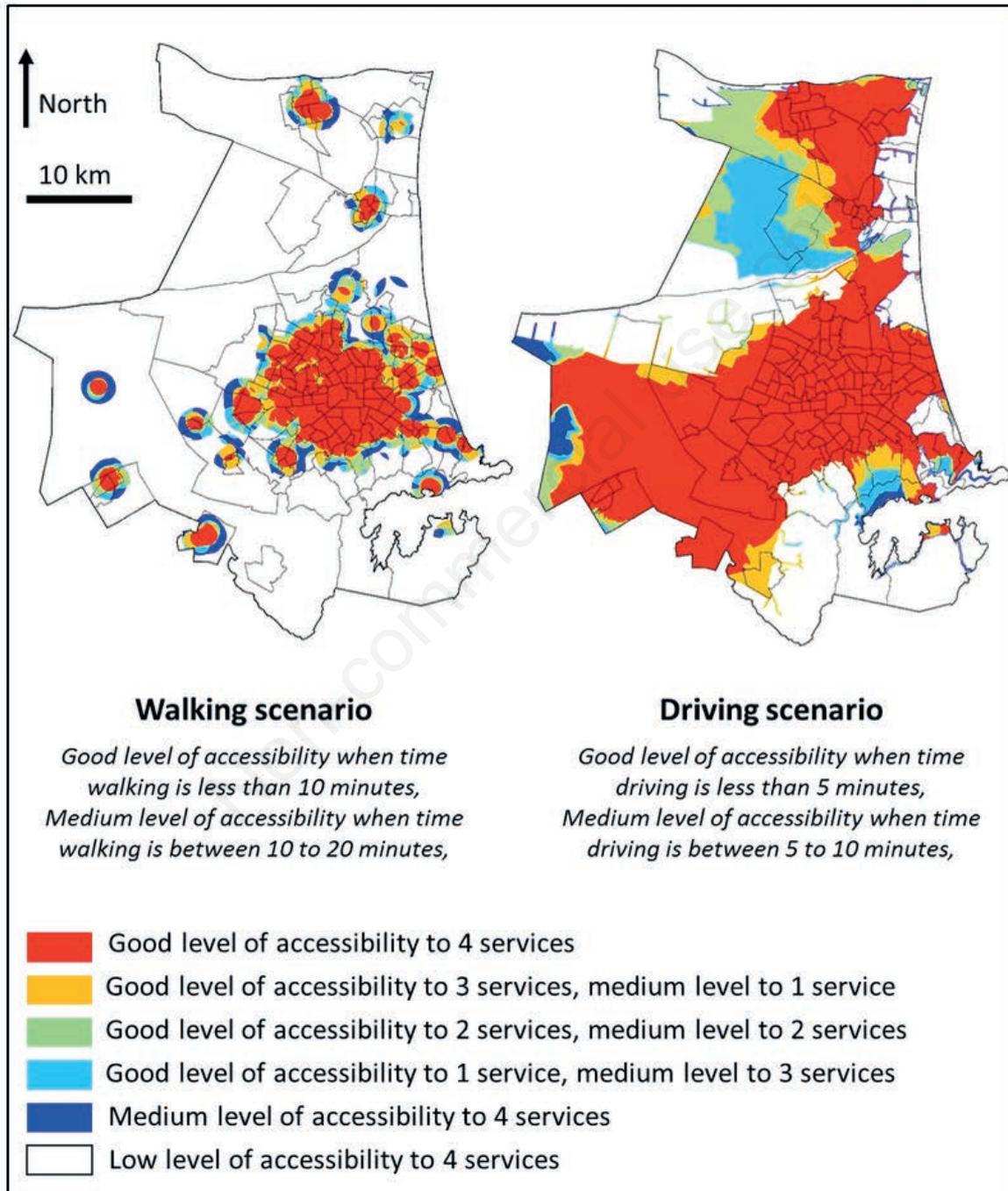


Figure 4. Level of accessibility to one to four well-being type of services (*i.e.* health and welfare, community, cultural, sport and recreation) within a walking and a driving scenario, in the Christchurch - *Otautahi* catchment area.

## Discussion

### Study strengths and innovation

The main strength and innovative element of the study rely on the wide range of different sort of data and services merge together to analyse and model accessibility and optimization in a dynamic medium size city. We spatially merged together and analysed 9 health and well-being service types provided by 6 different type of data sources, which represent 36,037 entities (4,791 facilities and 31,246 green and blue entities). National scale analysis (like Pearce *et al.*, 2006; Wiki *et al.*, 2018) cannot use the specific service database we used, such as Community Information Christchurch (CINCH) which covers only the Christchurch City Council area. Although it is a fundamental resource for evaluating accessibility to community services, it does not exist for all the main NZ cities, although they may collect or collate their own similar data. One of the main strengths of this study is also a weakness from another point of view, because of the non-reproducibility and comparability across the main cities of the country.

Using Christchurch as a study case represents another strength of this study. Although Christchurch is considered as a successful resilient city, its architecture and community are still in a rebuilding process. This already connected community before the earthquakes helped to adapt after disaster and explains the high resilience level of the community (Thornley *et al.*, 2015). These accessibility analysis findings highlighted a very active community, as socio-cultural places were determined of very good coverage all around Christchurch and the whole catchment area.

### Limitations

The accessibility analysis and scenario modelling have been computed by a very common way regarding the rich literature of this type of processing (Neutens, 2015). However, we chose to develop the scenario analysis for two different travel mode: walking and driving. Our results have highlighted different disparities according to these two transport modes. The Christchurch Eastern suburbs are for example sparsely served depending on the walking or driving scenario. This result is however consistent with other accessibility studies highlighted the less service coverage for more deprived suburbs (Guagliardo, 2004; Zhou and Kim, 2013; Shah *et al.*, 2016). We note that the more or less complex GIS analysis method does not change these general trends. While car travel time seems to be well-estimated to local conditions (Beere, 2016), the walking speed used is based on the average passage by healthy young adults', and computed for a single walking speed. Several studies have shown that a walking speed can vary a lot depending on a wide range of parameters (age, height, weight, level of fitness, etc.). For example for people with LTCs like diabetes, obesity, or elderly people, the walking speed can vary from 6.5 km/h for healthy adults to 3 km/h for vulnerable ones (Camarri *et al.*, 2006; Chetta *et al.*, 2006; Adeniyi *et al.*, 2009). In the case of pedestrian suburbs' design, like the in-rebuilding-process Christchurch city centre, it should then be useful to take into account different walking speed thresholds to cover a more diverse population. Another way of improvement of this study rely on taking into account more transport modes like cycling or scootering, or the use of public transport. As NZ cities are currently investigating a lot of new transport modes (*e.g.* shared electric scooters, autonomous vehicles) (Ministry of Transport - *Te Manatu Waka*, 2016) it should be interesting to conduct this type of accessibility analysis when they will be settle in the new central Christchurch city.

### Future work: strengthening the community process

The accessibility and modelling findings can be used either for planning purposes, to improve welfare coverage for example, or for better connect people with their local communities. As it is already demonstrated that social connectedness improve mental health (Saeri *et al.*, 2018), it looks interesting to develop a complete and searchable web-map tool merging the large online resource already available like CINCH (<http://www.cinch.org.nz/>), Active Canterbury (<https://www.activecanterbury.org.nz/>), Sport Canterbury (<https://www.sporty.co.nz/sportcanterbury>), or Canterbury Men's Centre (<http://canmen.org.nz/>). Many of the places registered in these websites are already merged in the CINCH database. This is a great example of a community database, that groups together community places, cultural, sport and recreation activities, etc. that is up to date and almost complete according to the Christchurch City Council (CCC) database management team. Merging together all the available community information in a searchable web-map tool represents a key product for a successful analysis and for a successful community life. Moreover, spatial database are often complex and difficult to access for stakeholders, that makes decision planning and urban development even more difficult (Schindler *et al.*, 2018). Kingston (2007) has demonstrated by the use of a web-based mapping how citizens can improve services to local communities for a management purpose.

## Conclusions

This study demonstrates the planning potentials for a community, of an accessibility analysis and a model location optimisation, using a wide range of health and well-being services, in a medium-size city. Firstly, the curation of the database demonstrated the substantial amount, both in terms of quantity and in diversity, of the well-being and community services' in Christchurch. This illustrates the unique and genuine NZ culture, valuing high the community and volunteering process, and explains the high resilience level of the community (Grant, 2017; Kenney, 2019). Secondly, using GIS accessibility analysis and model computation, the results highlighted the multiple activity centres of Christchurch and the small urban satellite areas around the outer urban footprint of the city. Primary health care services like GPs and pharmacies are evenly distributed across the Christchurch catchment area, while welfare facilities even with more than a hundred of different places are sparsely and unevenly spatially distributed. However, the positive results remain for the more easily accessible socio-cultural places as well as for green and blue spaces, both for walking and driving, indicating an even spread across the city. This can be considered a positive result as these place have demonstrated positive impacts on mental health and well-being for the whole population (Carrus *et al.*, 2015; Dadvand *et al.*, 2015; Thompson and Aspinall, 2011). Thirdly, the location optimisation model showed a reasonable level of equity for accessibility (in terms of the number of people covered in a reasonable travel time or distance). For example, scenarios showed the improvement of accessibility equity can be reached by making community places available for primary health care. The findings of this study therefore demonstrate not only the usefulness of a spatial web mapping tool in its own right, but also the importance of understanding the spatial distribution of community resources for planning purposes and their potential ameliorative impacts on health and well-being.



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