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An Approach for Measuring Spatial Accessibility to Services/Facilities by Urban Community Aged Population

Ju Bai [1], Chen Chen[2], Gao Yu[3],Bi Kai[1], Lina Chen[4]

[1]National Geomatics Center of China, Beijing 100830, China -(baiju,bikai)@ngcc.cn
[2] Land Satellite Remote Sensing Application Center, MNR, Beijing 100048, China - 410208288@qq.com
[3] Information Center of Ministry of Natural Resources, Beijing 100830, China - gaoyu@infomail.mnr.gov.cn
[4] Geo-Compass Information Technology Co, LTD, Beijing 100142, China - 2930654132@qq.com

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Abstract

Population aging is a global trend and a world-wide challenge to many governments. The high-quality life of the elderly cannot be separated from the support of basic services and facilities. Therefore, it is necessary to conduct analysis and research on the accessibility of urban community services and facilities. It is worth noting that the research in this article is based on master thesis (Bai, 2013). Drawing on the data, methods, and conclusions from the master's thesis, in this paper, an approach is designed for measuring spatial accessibility to services/facilities by a spatially dispersed ageing population in urban areas. The local government area (LGA) of Monash in the Melbourne metropolitan area has been selected the case study area. This study combines GIS-based spatial analytical procedures and two-step floating catchment area (2SFCA) method, in conjunction with mesh block level 2011 population data, service/facility data and transportation network data, to measure and map spatial variations in potential accessibility to services and facilities deemed essential to the aged population. Service facilities considered in the study include bus stops, train stations, bank facilities, shopping centres, post offices, churches, parks, public libraries, community centres, pharmacies, GP clinics and hospitals in Monash LGA. The research results can be used to optimize the spatial planning and layout of public facilities for ageing population.

1. Introduction

The process of population ageing is accelerating globally (Christensen et al., 2009). As the baby boomer generation enters old age, most countries around the world are facing the problem of increasing population aging (Harper, 2014). According to the Department of Economic and Social Affairs of the United Nations, the number of persons aged 60 or over, on a global scale, will reach 2 billion in 2050, and close to 3 billion in 2100. And the number of persons aged 80 or over is estimated to grow to 392 million in 2050, and to 830 million in 2100 (Leeson, 2018). Therefore, improving the living security level of the elderly has become a hot topic of concern for the government, business community, and academic community.

The high-quality life of the elderly cannot be separated from the support of basic services and facilities. However, on the one hand, the aged population is spatially dispersed and their personal mobility is restricted. On the other hand, the spatial distribution of services and facilities are not uniform across the urban space. In locations towards the outskirts of major urban centres, public transport infrastructure is inadequate and services/facilities are generally only readily accessible by car. For elderly people with limited mobility and living in the suburbs, accessibility to a range of services and facilities will become a major issue for them (Liu and Engels, 2012). Therefore, it is necessary to conduct analysis and research on the accessibility of urban community services and facilities (Wang et al., 2021).

In this paper, an approach are designed for measuring potential spatial accessibility to services/facilities by a spatially dispersed ageing population in urban areas. In general, the concept of spatial accessibility is considered to have three key components: demand for services, supply of services, and transportation network connecting the points of demand and supply (Bocarejo and Oviedo, 2012). In this study, the concept is further decomposed into two parts. One is described as the degree of convenience for residents to access public services and facilities. The other one is the level of social services in a specific urban community. "The degree of convenience for residents to access public services and facilities" is measured by the travel distance via a road network (Wang S et al., 2020). And "the level of social services in a specific urban community" is measured as weight value between locations of demand and provision by a modified two-step floating catchment area (2SFCA) method (Chen and Jia, 2019). Using census data, service/facility data, and transportation network datasets, conduct spatial analysis experiments to measure and map potential spatial changes in access to services and facilities considered crucial for the elderly population. Section 2 introduces study area selection and data collection. Section 3 introduces one method for measuring spatial accessibility to services/facilities. Section 4 introduces the experimental results. In Section 5, concludes this work.

2. Study Area and Data Set

To reveal accurate spatial accessibility variation in access to essential services and facilities by the aged population in urban areas, this paper selected the case study area in the local government area (LGA) of Monash in the Melbourne metropolitan area. Due to the high concentration of elderly people (aged 65 and above) in this region, and the collection of comprehensive questionnaire survey data on the use of public service facilities by elderly people（table 1).

Suburb (SA2)	Aged Population	Total Population	Aged Concentration
Ashwood – Chadstone	2360	16258	14.52%
Clayton	2113	16890	12.51%
Glen Waverley – East	4088	20725	19.73%
Glen Waverley - West	3308	18485	17.9%
Hughesdale	917	7056	13%
Mount Waverley - North	3039	14906	20.39%
Mount Waverley - South	3471	17155	20.23%
Mulgrave	2972	17653	16.84%
Oakleigh-Huntingdale	3060	20138	15.2%
Wheelers Hill	3836	19116	20.07%
Total	29164	168382	17.32%

Table 1. Concentration of the aged population in each suburb in the study area in 2011.

The data of transportation infrastructure in the study area, including road networks and public transportation services, is collected for spatial analysis. In addition to an average road density of 11.3 km/km^2, the study area also has 3 railways with a total length of 21.2 km, 15 railway stations, 82 bus routes with a total length of 775.1 km and 1626 bus stops for public transport services. Data for the location of the railways, railway stations, bus routes and bus stops that fall within the buffered study area were ascertained from the data supplied by the Victorian Department of Transport and the DSE VICMAP database. Train and bus service frequency data have been collected from the PTV website.

Through on-line databases and various public data website such as Google Maps and the Monash City government releases data, the locations of different types of services and facilities have been accurately labeled. Distribution of selected types of services and facilities in the study area is shown in Figure 1.

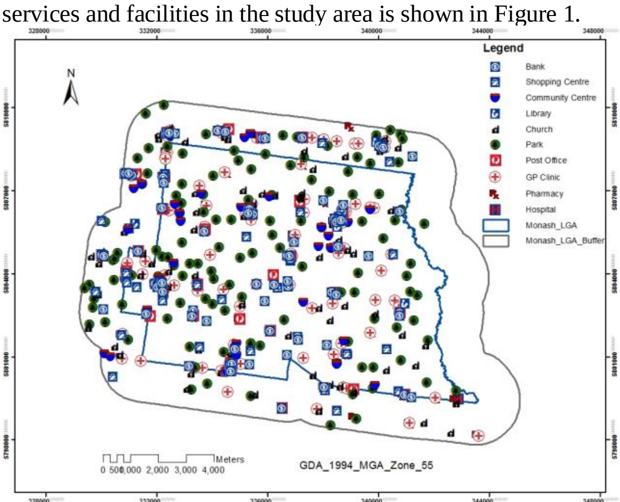

Figure 1. Distribution of selected types of services and facilities in the study area in 2011.

To minimize edge effects, this study included both transportation and service/facility data within a buffered study area in the spatial analysis. The 1.5 km buffer distance was based on the principle of living locally (or a ‘20 minute’ city) advocated recently for Melbourne and for the fact that the distance covered in a 20 minute walk by an aged person is about 1.5 km. After all the related data sets are collected, they are then imported to an ArcGIS Geodatabase.

3. Method for Measuring Spatial Accessibility to Services/Facilities

3.1 Measuring Access to Services/Facilities

Measures of spatial accessibility include opportunity-based measures, ratio-based measures, travel impedance-based measures, and gravity-based measures, utility-based measures and space-time measures. The accessibility of each Mesh Block (MB) to bus stop/train station is measured by the shortest travel distance via the road network. Measures of spatial accessibility include opportunity-based measures, ratio-based measures, travel impedance-based measures, and gravity-based measures, utility-based measures and space-time measures. The accessibility of each Mesh Block (MB) to bus stop/train station is measured by the shortest travel distance via the road network. This travel impedance based measurement considers all three key components of accessibility. Focuses on the spatial separation element， and ignores the quantitative relationships between the demands approximated by the number of aged persons associated with the residential MBs. And approximates the service capacity by the service frequencies associated with the bus stops or train stations. By taking into account all the three key elements of accessibility and the quantitative relationships between the number of aged persons at the MBs and the service frequencies at the stops/stations, the modified 2SFCA method have been implemented as followed:

Step 1: At each bus stop/train station j, the number of bus/train services S_j that utilise the stop/station are recorded. Search all residential MBs (represented as the centroid of the MB) k that lie within a threshold distance d_0 of location j and compute service provision-to-population ratio R_j the stop/station:

$$R_j = \frac{S_j}{\sum_{k \in (d_{kj} \le d_0)} P_k W_{kj}}$$

(1)

Where S_j is the number of bus/train services that utilise stop/station j during one workday period; P_k is the population count at location k that lies within the service area catchment j (i.e. $d_{kj} \le d_0$); d_{kj} is the shortest network distance between locations k and j; d_0 is the threshold distance (in this case, 800 m was set for bus stops and 2800 m was set for train stations, process of the derivation of d_0 value is shown in Table 5.1); and W_{kj} is the distance-decay weighting.

Step 2: At each residential MB k, search all bus stops/train stations j that lie within a threshold distance d_0 of location k, summate the ratios obtained from Step 1 for each stop j, using the shortest network distance between population location k to bus stop/train station j weighted by the distance decay W_{kj}:

$$A_k = \sum_{j \in (d_{kj} \le d_0)} R_j w_{kj}$$

(2)

Using Butterworth filter, the distance-decay weighting values are calculated as followed:

$$W_{kj} = \frac{1}{\sqrt{1+(d_{kj}/\beta)^n}}$$
(3)

Where $\beta = \frac{d_0}{400} * 250, n = 6$, and d_{kj} is the shortest network distance from the residential location k to bus stop *j*.

Calculated access to bus stop (A_{kj_bus}) and access to train station (A_{kj_train}) were then standardized into the range between 0 and 1 using the following equation:

$$S_{kj} = \frac{A_{kj} - A_{\min\_j}}{A_{\max\_j} - A_{\min\_j}}$$
(4)

Where A_{kj} is the accessibility to type *j* service/facility measured by the 2SFCA method from the population centre of MB_k, while $A_{min,j}$ and $A_{max,j}$ are the smallest and largest value of access (A_{kj}) to their respective type j service/facility from all MB population centre.

By comparing S_{kj_bus} and S_{kj_train}, the overall access to public transport T_k from MB *k*, is calculated as:

$$T_k = \begin{cases} S_{kj\_bus}, S_{kj\_bus} \geq S_{kj\_train} \\ S_{kj\_train}, S_{kj\_bus} < S_{kj\_train} \end{cases} \quad (5)$$

A MB having a smaller T_k value has relatively poorer accessibility to public transport, whereas a MB having a larger T_k value has relatively better accessibility to public transport.

Similar to the measurement of accessibility to bus stop/train station and public transport, the network distance to the nearest service/facility method and the 2SFCA method are also applied for measuring accessibility to other services/facilities. The threshold distance d_0^j for type j service/facility is decided by the average travel distance from all residential MBs to their respective nearest type j service/facility, and set as an integral multiple of 400m. The process for the derivation of d_0 and the resultant values of d_0 for the 12 types of selected services/facilities are summarised in Table 5.1.

Different to the method used to measure accessibility to public transport, a weighted linear combination method (Liu and Engels 2012) have been adopted to measure the overall accessibility to a range of selected services/facilities, as followed:

First, for each of the selected types of services/facilities, road network distances between the population centres of each MB to its nearest service/facility d_{kj} is calculated and standardized using the Eq. (6) and access A_{kj} to service/facility measured by the 2SFCA method is standardized using the Eq. (4).

$$D_{kj} = \frac{d_{kj} - d_{\min\_j}}{d_{\max\_j} - d_{\min\_j}} \quad (6)$$

Where d_{kj} is the road network distances between the population centre of MB_k to its nearest type *j* service/facility, while $d_{min,j}$ and $d_{max,j}$ are the shortest and longest road network distances between all MB population centre to their respective nearest type j service/facility.

Then the overall accessibility to a range of different types of services/facilities from MB centroid OA_d and OA_{2SFCA} can be calculated as followed:

$$OA_d = \sum_{j=1}^{10} w_j D_{kj}$$
(7)

$$OA_{2SFCA} = \sum_{j=1}^{10} w_j S_{kj}$$
(8)

Where D_{kj} and S_{kj} is the standardized accessibility to the type j service/facility from MB centroid k, measured by the network distance to nearest service/facility method and by the modified 2SFCA method respectively; $\sum w_j = 1$ and w_j is the weight value assigned for type *j* service, as listed in Table 2.

Service type j	**w_j**
Bank	0.1178
Shopping centre	0.1298
Community centre	0.1330
Public library	0.0629
Church	0.0725
Park	0.0661
Post office	0.1154
GP clinic	0.1298
Pharmacy	0.1194
Hospital	0.0533
Total	1.0000

Table 2. The weightings wj for different types of services/facilities.

This weight value w_j can be applied to the results of both travel impedance based measures and the measures calculated with the modified 2SFCA method. For the travel impedance based measures, smaller values indicate closeness or more convenient locations, larger values indicate remoteness or less convenient locations. For the accessibility measured by the modified 2SFCA method, the smaller the A_k values the less advantageous the MB is, whereas the larger the A_k values the more advantageous the MB becomes.

3.2 The Enhanced 2SFCA Method

The level of social services in a specific urban community is measured by a modified 2SFCA method. The original 2SFCA method has been used in a number of recent studies measuring health care accessibility (Kanuganti et al., 2016). However, this method has two limitations (Luo and Qi, 2009): (1) it does not differentiate distance impedance within the catchment; and (2) it is a dichotomous measure.

Luo and Qi (Luo and Qi, 2009) synthesized these ideas of improvement in the enhanced two-step floating catchment area (E2SFCA) method to improve the 2SFCA method, while maintaining theoretical connection with the gravity-based measure and its associated advantages. The E2SFCA method enhanced the 2SFCA method by applying weights to differentiate travel time zones, in both steps, thereby accounting for the effect of distance decay. In order to differentiate accessibility within a catchment, multiple travel time zones within each catchment are obtained using GIS and assigned with different weights according to the Gaussian function. Luo and Qi (2009) compared analysis results of spatial access between two sets of Gaussian weights corresponding to sharp and slow distance decay. Weight set 1 (=1.00, 0.68 and 0.22 for the three travel time zones) represents the slower distance decay; weight set 2 (=1.00, 0.42 and 0.09) represents the sharper distance decay.

It is implemented in two steps to measure accessibility to physicians. Firstly, the catchment of provider location j is defined as the area within a 30-min driving zone. Within each catchment, compute three travel time zones with minute breaks of 0-10 min, 10-20 min and 20-30 min (zone 1-3, respectively). Search all population locations (k) that are within a threshold travel time zone (Dr) from location j (i.e. catchment area j), and compute the weighted provider-to-population ratio, Rj, within the catchment area as follows:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_r\}} P_k W_r} = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_1\}} P_k W_1 + \sum_{k\in\{d_{kj}\in D_2\}} P_k W_2 + \sum_{k\in\{d_{kj}\in D_3\}} P_k W_3} \quad (9)$$

Where Pk is the population of grid cell k falling within the catchment j ($d_{kj} \in D_r$); Sj is the service capacity of provider site j; dkj is the travel time between k and j; Dr is the rth travel time zone (r=1-3) within the catchment; and Wr is the distance weight for the rth travel time zone calculated from the Gaussian function, capturing the distance decay of access to the provider j.

Secondly, for each population location i, search all provider locations (j) that are within the 30 min travel time zone from location i (i.e. catchment area i), and sum up the provider-to-population ratios (calculated in step 1), Rj, at these locations as follows:

$$A_i^F = \sum_{j\in\{d_{kj}\in D_r\}} R_j W_r = \sum_{j\in\{d_{kj}\in D_1\}} R_j W_1 + \sum_{j\in\{d_{kj}\in D_2\}} R_j W_2 + \sum_{j\in\{d_{kj}\in D_3\}} R_j W_3 \quad (10)$$

Where A_i^F is the accessibility of population at location i to physicians; Rj is the provider-to-population ratio at provider location j that falls within the catchment centred at population i (that is, $d_{kj} \in D_r$); dij is the travel time between i and j and the same distance weights (Wr) derived from the Gaussian function used in step 1 are applied to different travel time zones to account for distance decay.

The enhanced 2SFCA method is essentially a weighted physician-to-population ratio, and it can be easily implemented with spatial analysis technology. This study applied spatial analytical approach to accurate spatial resolution census data, service/facility data and transport network datasets to measure and map the spatial variations in potential accessibility to services and facilities deemed essential to aged population, including bank facilities, shopping centres, post offices, churches, parks, public libraries, community centres, pharmacies, GP clinics and hospitals in the local government area of Monash (Radke and Mu, 2000).

The key tasks that made up of this methodology include: (1) collect required datasets in the study area and organize the datasets into a geodatabase; (2) disaggregating the 2011 Census data from the SA1 (for 2011 Census) into the respective MB units, through land-use constrained and address-point weighted areal interpolation; (3) calculating a set of access measures for each MB in the study area in terms of shortest network distance to single type, multi-type, or all selected types of services/facilities and by means of a modified 2SFCA procedure, to reveal the spatial variations in access from MB-based residential locations to services/facilities deemed essential to the normal life of aged persons; and (4) detecting changes, and spatial clusters in these calculated access measures, to establish a foundation for better understanding or improvement of the revealed spatial patterns of services/facilities accessibility by the aged population in the study area.

3.3 Access to a Service/Facility Measured by the Modified 2SFCA Method

The enhanced 2SFCA method is adopted in measuring spatial accessibility to services/facilities, taking into account the population size at each MB centroid, the level of service provision at each facility (wherever data are available), as well as the distance decaying effects.

Access to each type of service/facility has been measured with the enhanced 2SFCA method, using specific maximum and threshold distances derived from the measured mean shortest network distances to services/facilities for different types of services/facilities. Figure 2 to Figure 3 present the 2011 spatial variations in access to the GP clinic and bank, using levels (quintiles) of accessibility values measured by the enhanced 2SFCA method.

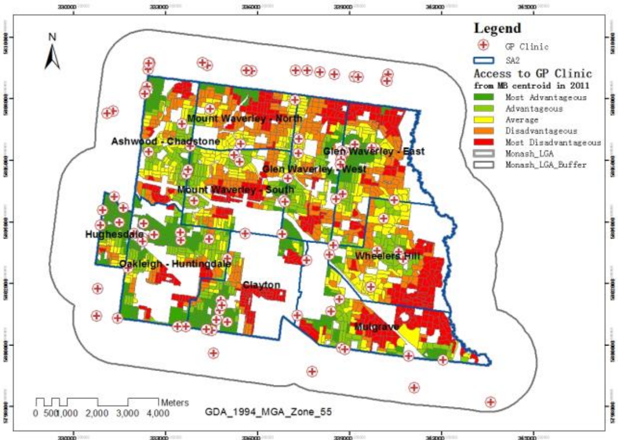

Figure 2. The 2011 spatial pattern of access to GP clinics measured by the modified 2SFCA method (d0 =1200).

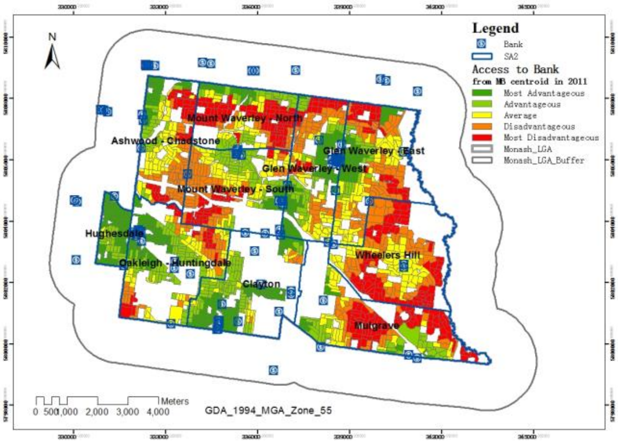

Figure 3. The 2011 spatial pattern of access to banks measured by the modified 2SFCA method (d0 =1600).

Results derived from the modified 2SFCA method suggest that there is a similar rank of the 10 types of services/facilities compared to the one suggested by the network distance to nearest service/facility method:

Rank order based on the mean network distance to nearest service/facility (from small to large): park < GP clinic < church

< pharmacy < bank < shopping centre < post office < community centre < public library < hospital.

Rank order based on the log-transformed median value of accessibility calculated by the modified 2SFCA method (from large to small, see Table 3): park > GP clinic > bank > church > pharmacy > community centre > shopping centre > post office > public library > hospital.

$\log(A_k)$	Min	Max	Mean	Median	Std. Dev.
Park	-8.27	-2.61	-5.96	-5.85	0.97
GP clinic	-8.07	-2.51	-6.36	-6.16	1.17
Bank	-8.68	-2.47	-6.47	-6.33	1.36
Church	-9.40	-2.78	-7.19	-6.69	1.71
Pharmacy	-8.12	-2.65	-6.79	-6.75	1.13
Community centre	-9.04	-3.53	-7.32	-7.06	1.21
Shopping centre	-8.81	-3.51	-7.13	-7.08	1.22
Post Office	-8.63	-3.93	-7.32	-7.27	1.02
Public library	-9.47	-5.49	-8.39	-8.54	1.04
Hospital	-10.23	-6.42	-9.29	-9.66	1.04

Table 3. Summary statistics of log-transformed accessibility values calculated by the modified 2SFCA method.

4. Result and Discussion

The MB-based number of aged persons has been used as a proxy for representing and measuring the amount of demand. The spatial layout and relationship among bus stop, bus routes, train station, railway lines, and road centrelines have been used to illustrate the spatial variation in transportation infrastructure and support measuring spatial access to transportation in the study area. For public transport, service frequency at each bus stop or train station has been used to represent the level of service or the degree of attractiveness at the location of service provision. A set of quintiles-based thematic maps have been used to present spatial variation in measured/calculated access to individual types of services or facilities. Figure 4 shows the spatial variation for changes in access to public transport measured by the accessibility values calculated from the enhanced 2SFCA method. Figure 5 shows spatial clusters of residential locations with improved (blue), worsened (red, and unchanged (yellow) access to public transport, and Figure6 shows spatial clusters of residential locations with improved (blue), worsened (red, and unchanged (yellow) overall access to services/facilities.

Across the study area and on average, about 34% of the aged population have a better than average overall accessibility but close to 45% of the aged population have a worse than average overall accessibility. By locality, Clayton has the best overall accessibility but Wheelers Hill has the worst; significant clusters of disadvantaged Mesh Blocks are found in southwest Mount Waverley, northeast Mount Waverley and northwest Glen Waverley, north Mulgrave and most of Wheelers Hill. By simply overlaying the MBs with high concentration of aged persons and MBs with poor overall accessibility, spatial clusters of disadvantaged MBs (with both poor overall accessibility to services/facilities and high concentration of aged persons) can be clearly identified in south Oakleigh, in northeast, southeast and southwest Mount Waverley, in northeast and southeast Glen Waverley, in southeast Wheelers Hill, and in northwest Mulgrave.

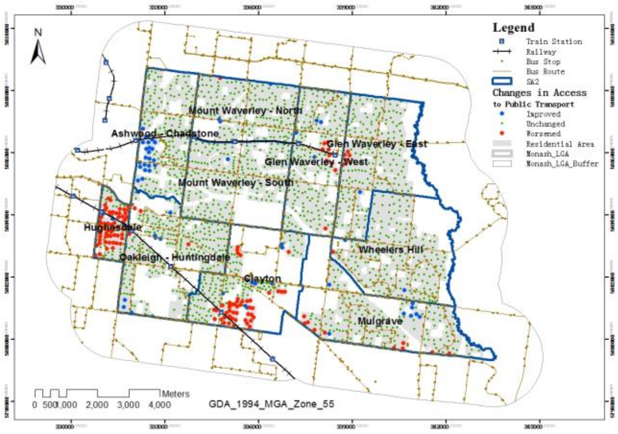

Figure 4. The spatial pattern of access to public transport change measured by the enhanced 2SFCA method over the study area between 2006 and 2011.

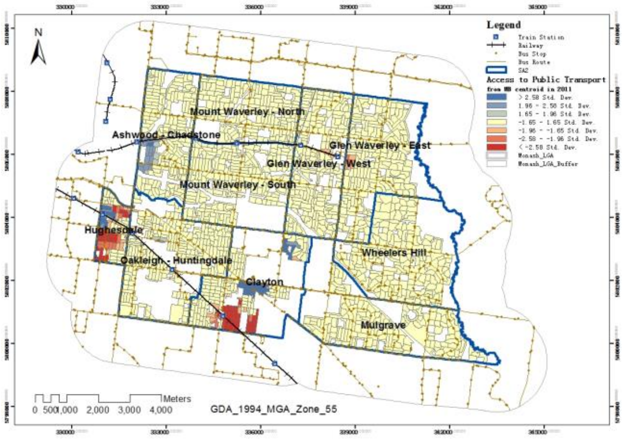

Figure 5. The spatial clusters of public transport access change measured by the modified 2SFCA method over the study area between 2006 and 2011.

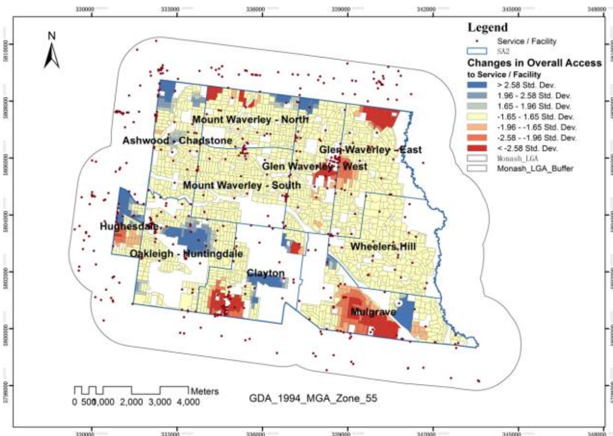

Figure 6. The spatial clusters of overall accessibility change measured by the modified 2SFCA method over the study area between 2006 and 2011.

5. Conclusion

This study proposes an approach for measuring potential spatial accessibility to service or facilities by urban community aged population. The approaches taken and the findings made in this study would be supportive to public policy makers, government and non-government service providers for the effective implementation and continuous improvement of the outcome of the ‘ageing in place’ strategy. The research findings will be useful to aged people and their family as guidance to select their suitable place of residence as well.

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