CHAPTER 4 RESULTS

Once processed, the intersection, dwellings, land use and retail data are used to create a series of measures. These measures are used to create different permutations of the walkability index. These measures are presented in this chapter as part of the process of creating an objectively derived measure of the physical environment for the urban CCDs in Adelaide Statistical Division. The measures are included as actual values, density and deciles as part of the process of understanding the pattern and creating a basis for calculating the walk index from a range of different data sets. The outcomes are presented in more detail below.

4.1 Measures of Connectivity

The processing of intersections detailed in the previous chapter results in both the number and the potential directions of travel for each intersection. In addition, the road lengths and the number of routes are calculated as part of the measures development. The measures included in the intersection results include:

- Number of intersections;
- Direction of travel per intersection;
- Direction of travel, minus one (as an indicator of the likely travel choices assuming the person would arrive at the intersection from a

given direction and would be likely to choose a different direction of travel);

- Route number; and
- Road length.

A series of derived measures were calculated using the measures listed above, these include:

- Intersection density (number of intersection/CCD Area);
- Weighted intersection density ((intersection X direction)/CCD area);
- Weighted intersection –1 density (as above, but using the direction minus one value);
- Connectivity measure;
- Gamma index;
- Eta index;
- Intersection to road length ratio;
- Intersection with 3 or more directions of travel; and
- Cul-de-sacs.

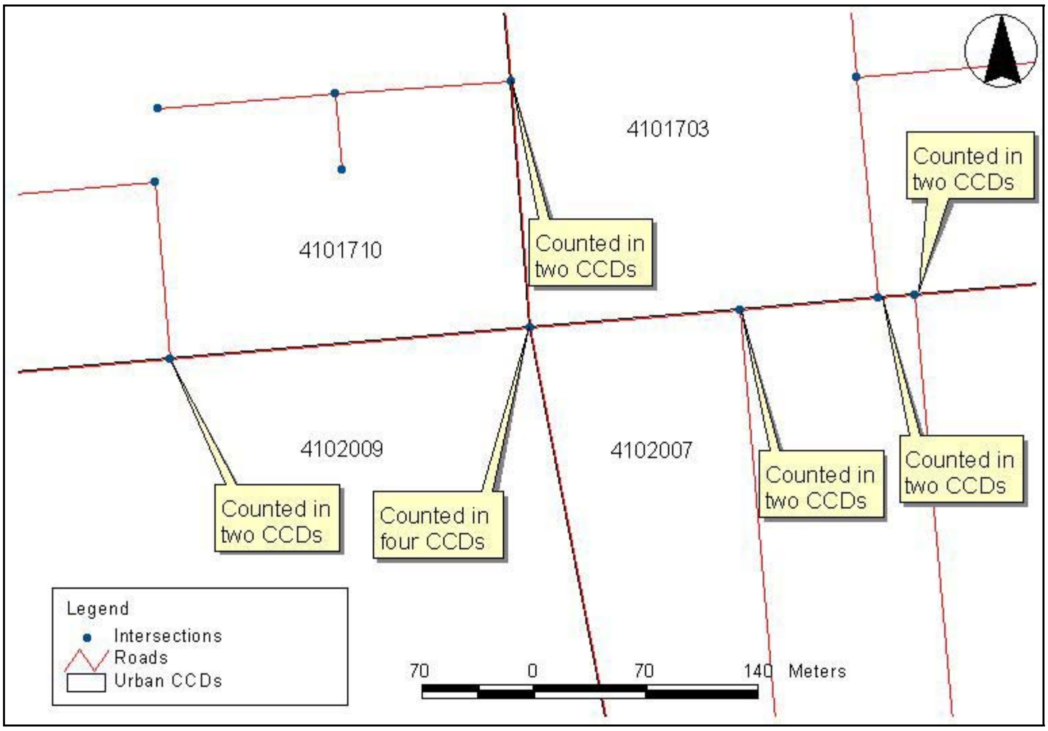
The measures and derived measures are combined to form different variants of the connectivity elements of the walk index.

4.1.1 Measures of Connectivity: Intersection

There were 60077 intersections counted in the ASD urban CCD study area, although due to the CCD design rules where road centre lines are used to define CCD boundaries, intersections on CCD boundaries are counted multiple times. For example, at a four way CCD boundary the same intersection is counted four times, and at most CCD boundaries, the same intersection is counted twice (Figure 4.1). Consequently, the count of intersections may be overstated, however this reflects the fact that the same intersection is a valid inclusion for all CCDs which meet at the intersection.

Without the multiple counting of intersections there are 41014 intersections in the ASD study area. Five intersections are included five times (0.01%), 260 (0.6%) intersections are counted four times, 2506 (6.1%) intersection are counted three times, 13251 (32.3%) intersections are counted twice and the rest (24922 or 60.9%) are counted once. The majority of intersections are located within single CCDs, the rest are on CCD boundaries and are counted in two or more CCD (Figure 4.1)

Figure 4.1: Intersections along CCD Boundaries.

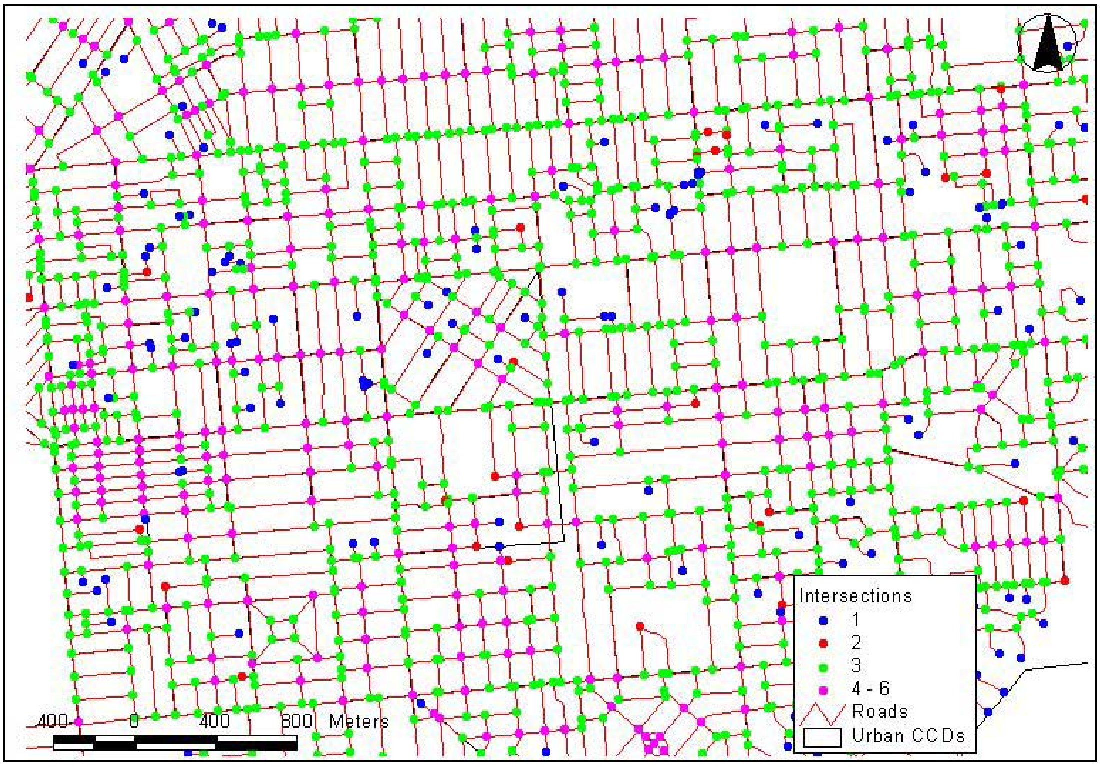


Source: ABS ASGC 2001; Road Centrelines, Planning SA.

Of importance when representing connectivity are the potential directions of travel at each intersection. As stated in the Chapter 3, the measure as applied in the US study only included intersections with three or more directions (Frank et al. 2005). In this study, while the intersections with three or more directions are used for creating the intersection measure, all intersections are included for other intersection measures, especially the cul-de-sacs. While the intersections with three or more directions of travel are a good indicator of connectivity, it is equally as important to recognise the importance of cul-de-sacs, especially in newer developed housing areas. Figure 4.2 an older inner urban area and Figure 4.3, a newer 1990s developed urban area display the importance of using all intersections. Older areas are more connected, traditionally built around a grid based street network, while newer urban developments are designed with a more curvilinear street network with numerous cul-de-sacs.

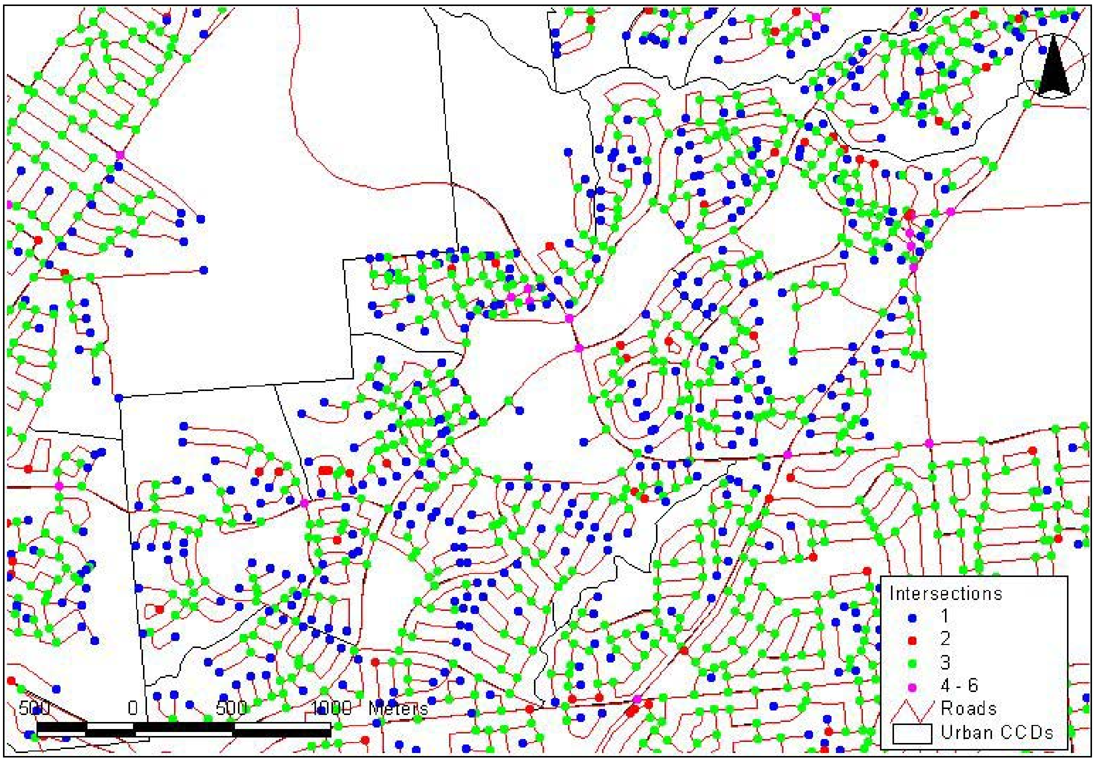
Figures 4.2 and 4.3 highlight the differences with fewer cul-de-sacs in the older area compared with a dominance of cul-de-sacs in the newer area. It is also noteworthy that the newer area is predominantly cul-de-sacs and three way intersections. In contrast the older area has more three and four way intersections. As a result the connectivity measures should reflect a more connected road network in the older urban areas and a less connected road network in the newer areas.

Figure 4.2: Intersection Directions, Older Inner Urban Area.



Source: ABS ASGC 2001; DCDB-LOTS; Road Centrelines, Planning SA.

Figure 4.3: Intersection Directions, Newer Urban Area.



Source: ABS ASGC 2001; DCDB-LOTS; Road Centrelines, Planning SA.

Table 4.1 displays the number and percent of intersections by CCD and by directions of travel. This table counts the number of CCDs with intersections by the potential directions of travel. From Table 4.1, cul-de-sacs are present in three quarters of all CCDs (73%), however, the remaining CCDs do not have any cul-de-sacs. One CCD has between 60 to 80 cul-de-sacs. Two direction intersections are mostly culled from the data set as these are usually a psuedo node, except where the street name changes. Over half the CCDs do not have two direction intersections with the remaining CCDs reporting between 10 and 20 two-direction intersections. Almost two thirds of all CCDs have between 20-40 intersections with three or more directions of travel. Three or more directions of travel are the most common form of intersection.

Table 4.1: Number of Intersections by CCD by Direction of Travel

Number of Intersections	One Direction		Two Directions		Three + Directions		All Directions	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
0	553	26.9	1167	56.8	0	0.0	0	0.0
<20	1480	72.0	889	43.2	650	31.6	477	23.2
<40	22	1.1	0	0.0	1263	61.4	1222	59.4
<60	0	0.0	0	0.0	132	6.4	303	14.7
<80	1	0.0	0	0.0	5	0.2	41	2.0
80-200	0	0.0	0	0.0	6	0.3	13	0.6
Total	2056	100	2056	100	2056	100	2056	100.0

The distribution of the number of intersections is shown in Figure 4.4, the density of intersections in Figure 4.5, the directions of travel in Figure 4.6 and cul-de-sacs in Figure 4.7. What is evident from these figures is that the larger CCDs (by area) have the greater number of intersections and cul-de-sacs. This outcome is hardly a revelation as the larger CCDs have more potential area and therefore will include a greater number of features. This is evident for many of the calculated values presented in this chapter. To overcome this skew towards the larger CCDs, many of these measures are presented as density calculations to provide a standardized value for valid comparisons. However, some raw values are included to provide the actual number and distribution pattern of the various connectivity measures to highlight the actual pattern and provide a reference for the standardized values.

Figure 4.4: Number of Intersections per CCD, ASD.

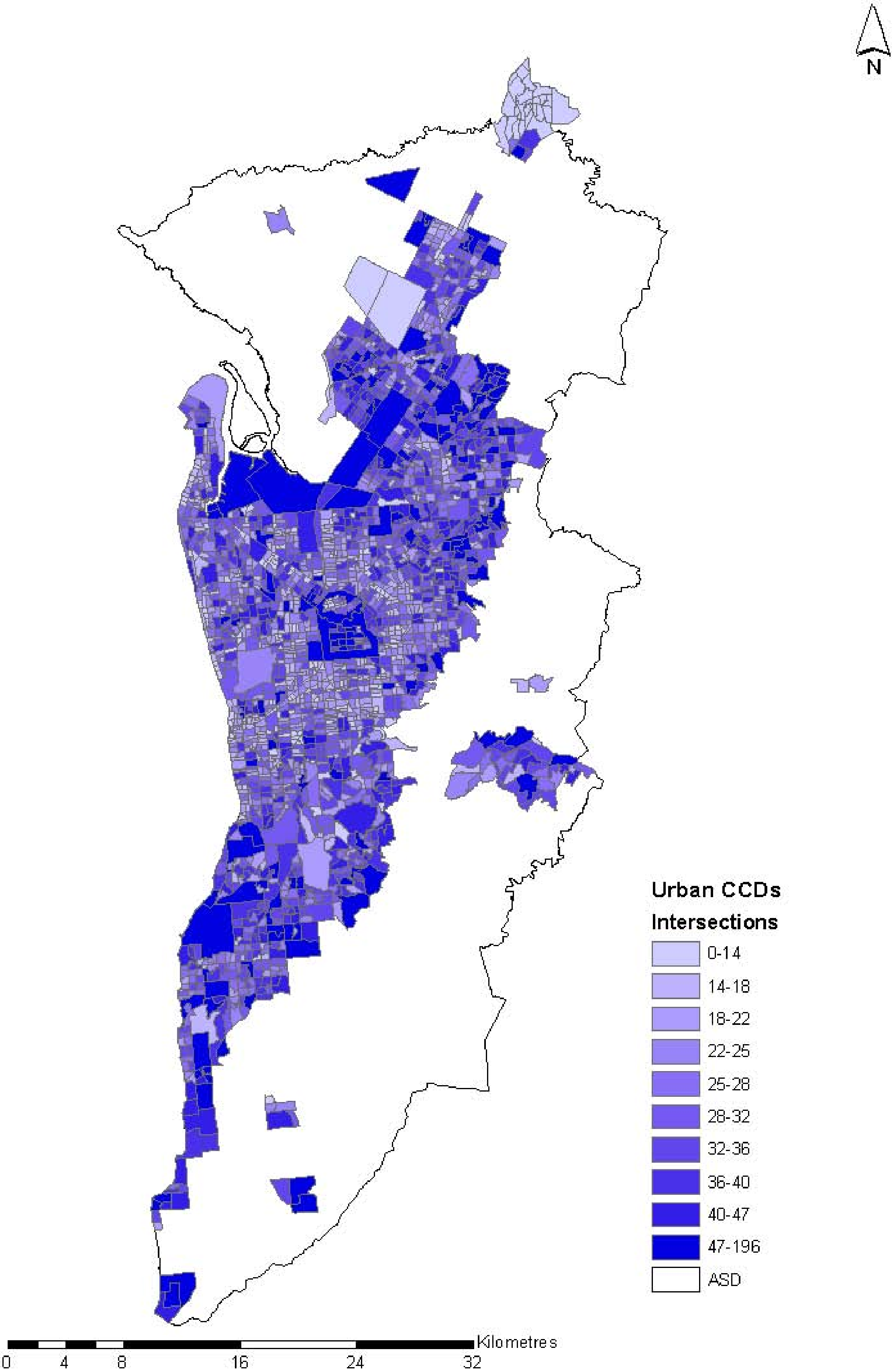
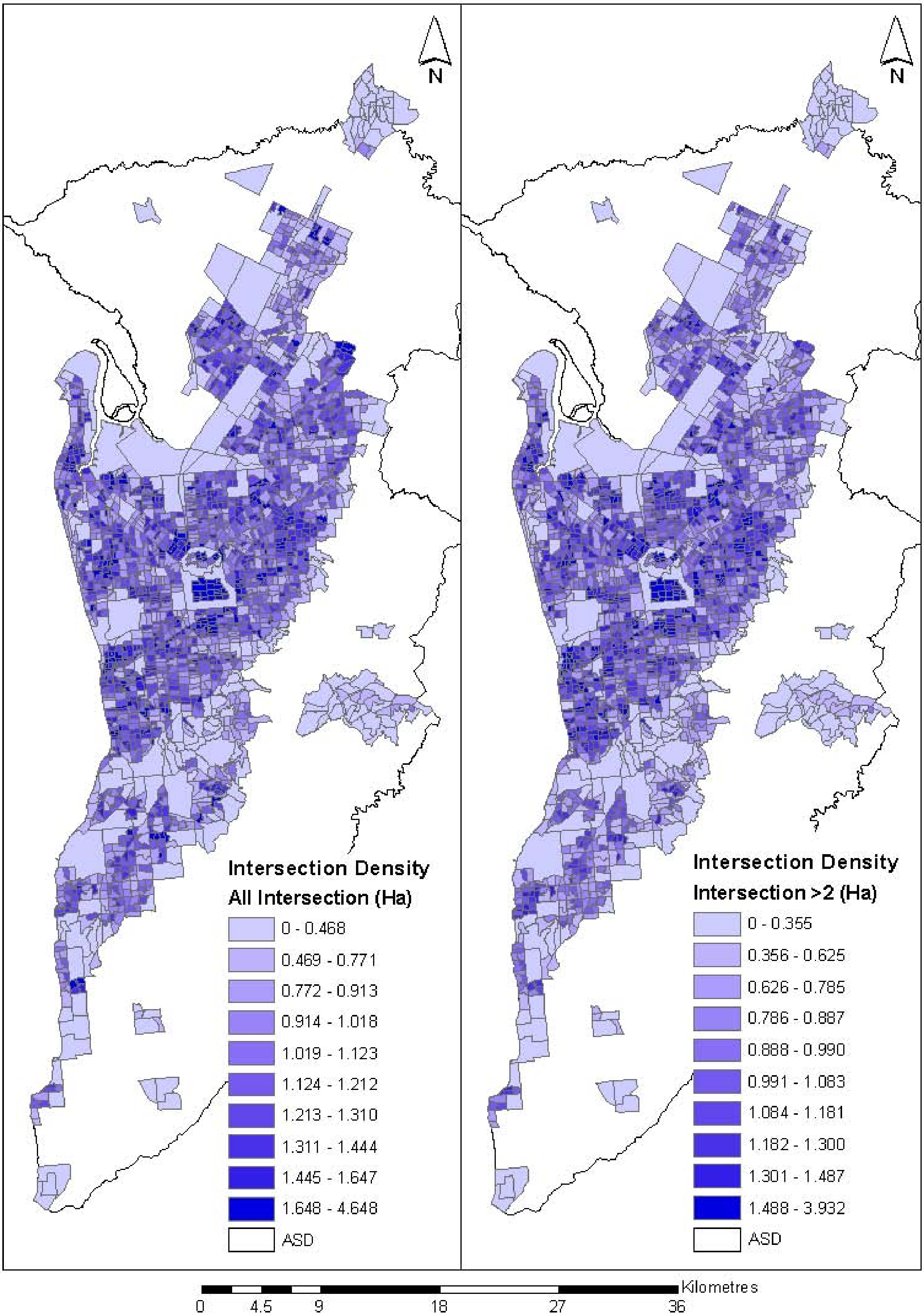


Figure 4.5: Density of Intersections per CCD, ASD.



The number of intersections per CCD ranged from 1 to 196. Intersections with three or more directions of travel ranged from 3 to 151. The average number of intersections per CCD was 29. The density of all intersections and intersection with 3 or more directions are shown in Figure 4.5 to emphasize the impact CCD area has on the measure. Note in particular, the changes in the larger CCDs, which were in the 10th decile in Figure 4.4, but are in the 1st and 2nd deciles in the density measure (Figure 4.5). If the actual number of intersections per CCD were the basis for the calculated walk index the results would bias towards large CCDs and not accurately reflect CCD connectivity. Figure 4.5 not only displays the differences between the actual number of intersections and density, it also highlights the variations in CCD ranking using all intersections and only those with three or more direction choices. The decile ranking with three or more directions removes the potential to bias the connectivity measure with CCDs with a large number of cul-de-sacs. To further quantify the directions of travel at each intersection, the potential directions of travel was used to calculate a total direction by each CCD. The value for each cul-de-sac was set to –1. Taking into account the cul-de-sacs, the directions of travel potential ranges from 0 to 518.

Table 4.2: Number of CCDs by Potential Travel Directions.

Potential Directions of travel	Number of CCDs	Percent
Less than 10	4	0.2
10 to 20	13	0.6
20 to 40	124	6.1
40 to 60	367	18.0
60 to 80	527	25.8
80 to 100	483	23.6
100 to 200	525	25.7
200 to 300	7	0.3
300 to 500	5	0.2
500 to 600	1	0.0
Total	2056	100.0

The majority of CCDs have between 60 to 200 directions on travel (75%), with 24% between 20 to 60; the rest have either less than 20 (0.8%) or greater than 300 (0.5%). The decile ranking of the number and density of CCDs travel directions are shown in Figure 4.6.

Figure 4.6: Directions of Travel per CCD, ASD.

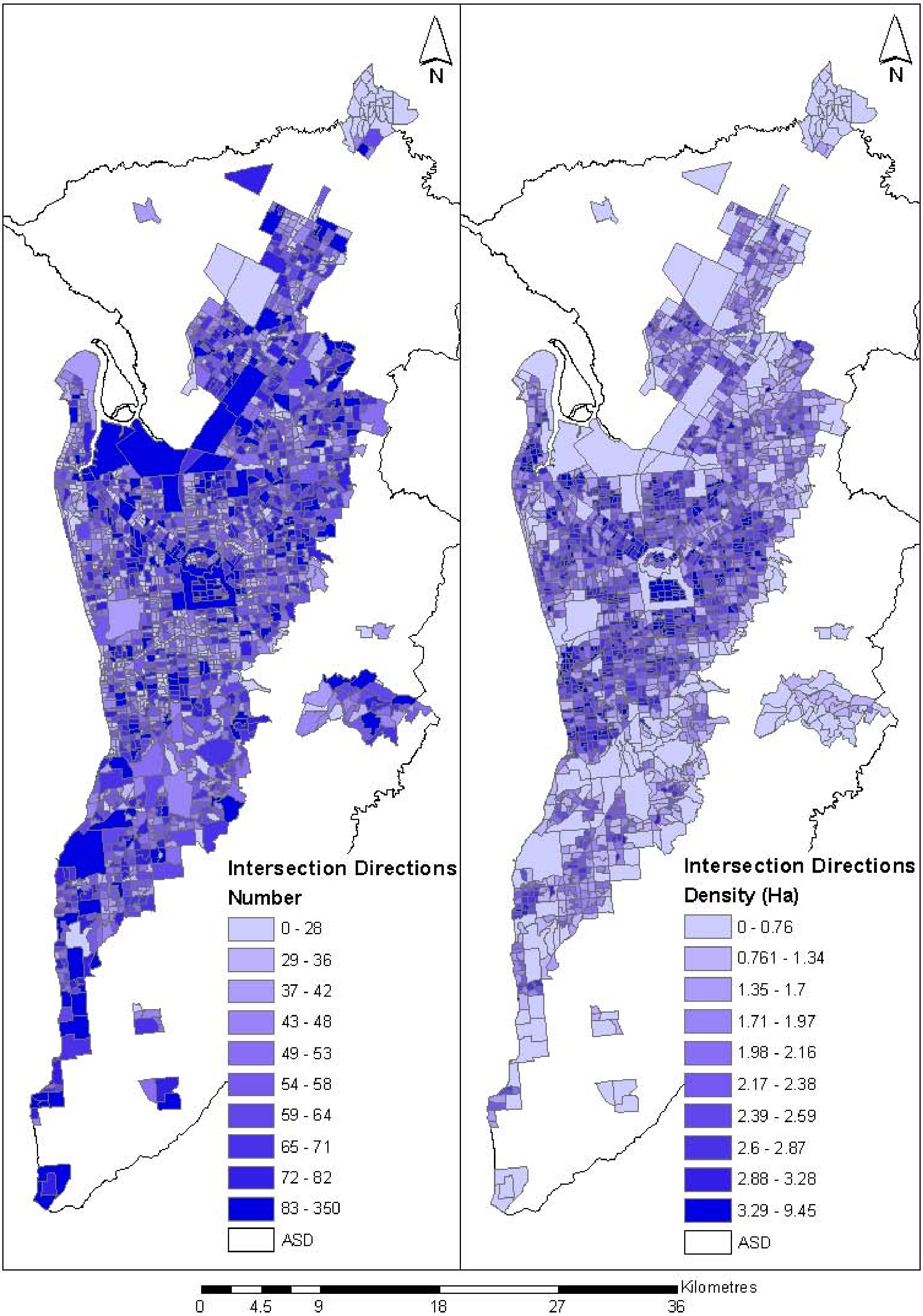
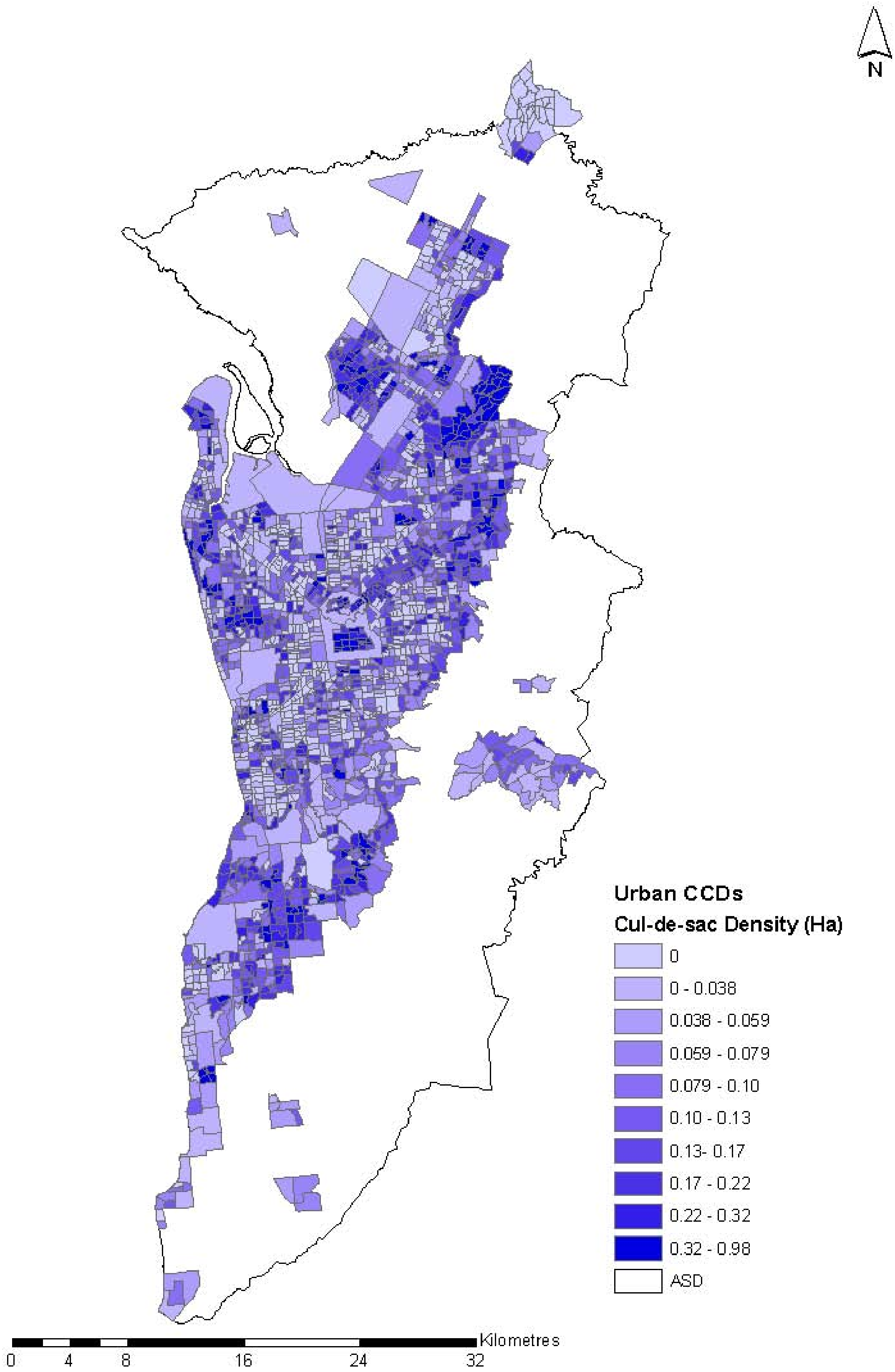


Figure 4.7: Density of Cul-de-Sac per CCD, ASD.



Cul-de-sacs are included as an impediment to connectivity and as stated earlier, newer areas should have more cul-de-sacs than the older inner areas. This is apparent in Figure 4.7, where the northeastern fringe, southern fringe and western areas have higher concentrations of cul-de-sacs than the inner area.

Another measure is the total number of streets per CCD. Streets are counted as all road arcs (line segments from node to node) with the same street name. Each segment is dissolved to create a single record (route) for each street name. These are counted for each CCD and displayed in Table 4.3 and Figure 4.8.

Table 4.3: Number of Street and Routes per CCD.

Number of Streets			Number of Routes		
10	223	10.8	100	203	9.9
<20	1213	59.0	<250	464	22.6
<30	540	26.3	<500	678	33.0
<40	62	3.0	<1000	523	25.4
<50	11	0.5	<1500	116	5.6
<60	2	0.1	<2000	38	1.8
<70	2	0.1	<3000	17	0.8
<80	1	0.0	<5000	10	0.5
<90	2	0.1	<10000	4	0.2
<100	0	0.0	<20000	3	0.1
	2056	100.0		2056	100.0

Eleven percent of CCDs have 10 or less streets, 60% have between 10 and 20 streets, and a further 26% have between 20 and 30 streets, with the rest between 40 to 90 streets. As stated in the previous chapter, routes are calculated as a relationship between intersections and links and as is evident from Table 4.3, a third of the CCDs have less than 250 routes (32%), two thirds have less than 500 routes (65%), a further 25% between 500 and 100 with very few greater than 1000. The number of streets and routes per CCD are shown in Figures 4.8 and 4.9.

Figure 4.8: Density of Streets per CCD, ASD.

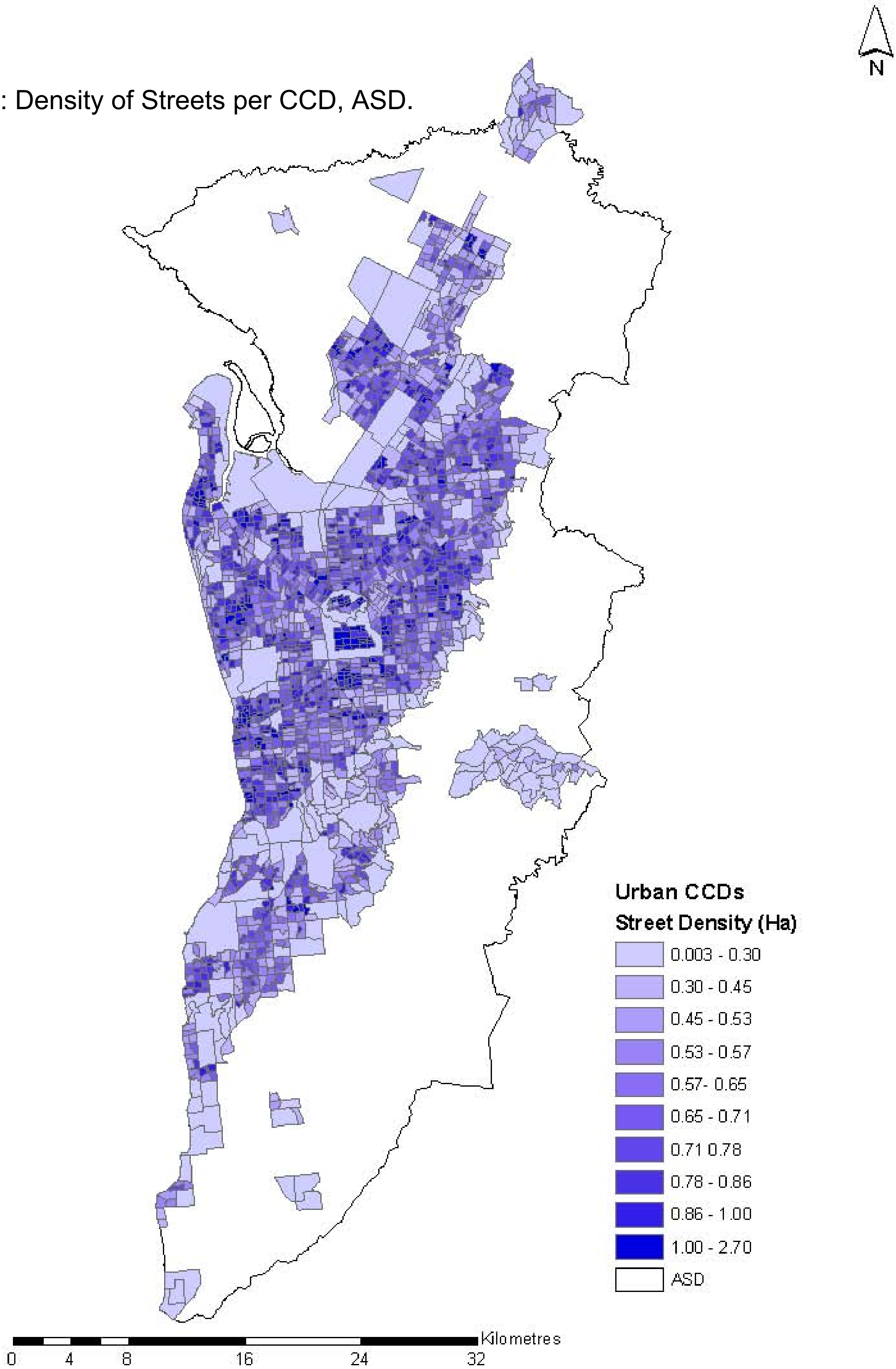
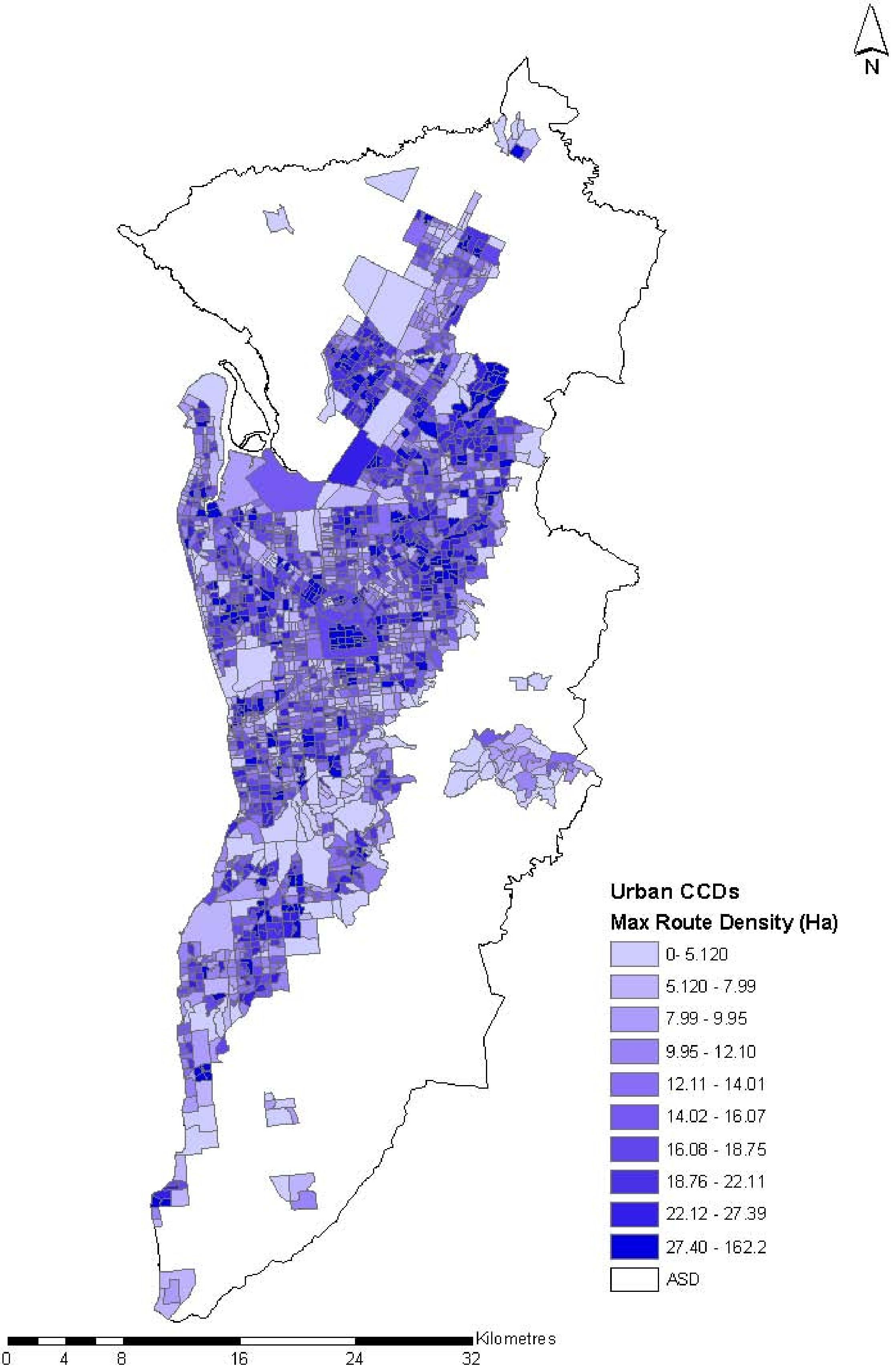


Figure 4.9: Density of Routes per CCD, ASD.



Network structure has been the subject of spatial analysis, especially by transport planning and engineering professionals. The two measures included in this research are the γ and α indices. As stated in chapter 3, these indices measure the ratio of actual links to the maximum possible number of links in a network (γ index) and the ratio of circuits to the maximum number of circuits in a network (α index). Generally, a better developed transportation network has higher values for these indices (Chou 1997).

The transport planning connectivity measures involve a series of sub-measures to derive the main indices. These include the length of roads by CCD, CCD maximum and minimum number of routes and the number of intersections. These measures are applied to both the total intersection data and for intersection with three or more directions of travel. All of these measures are presented as deciles in Figures 4.10 to 4.13.

Figure 4.10: Density of Route Length per CCD, ASD.

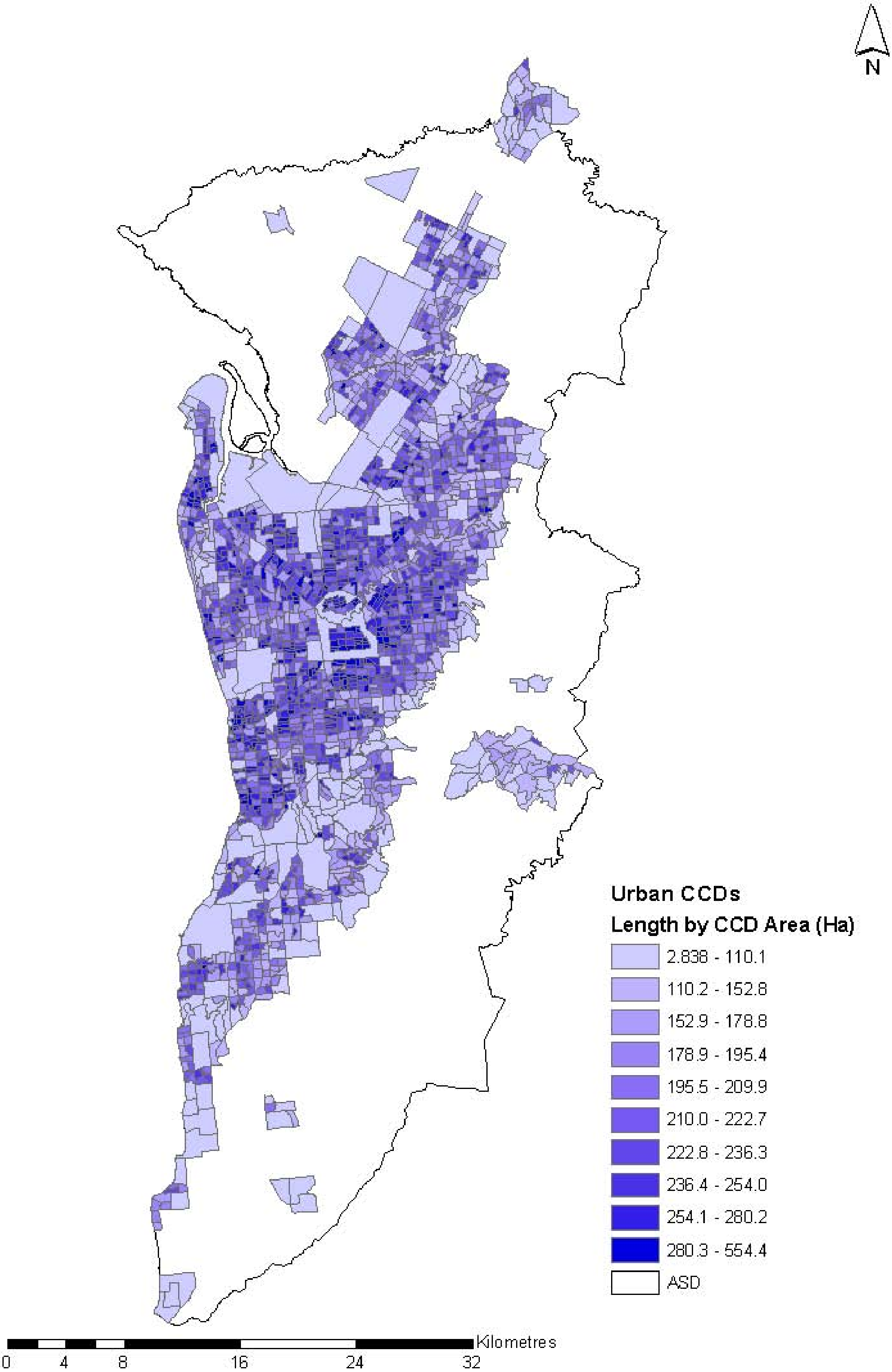


Figure 4.11: Connectivity per CCD, ASD.

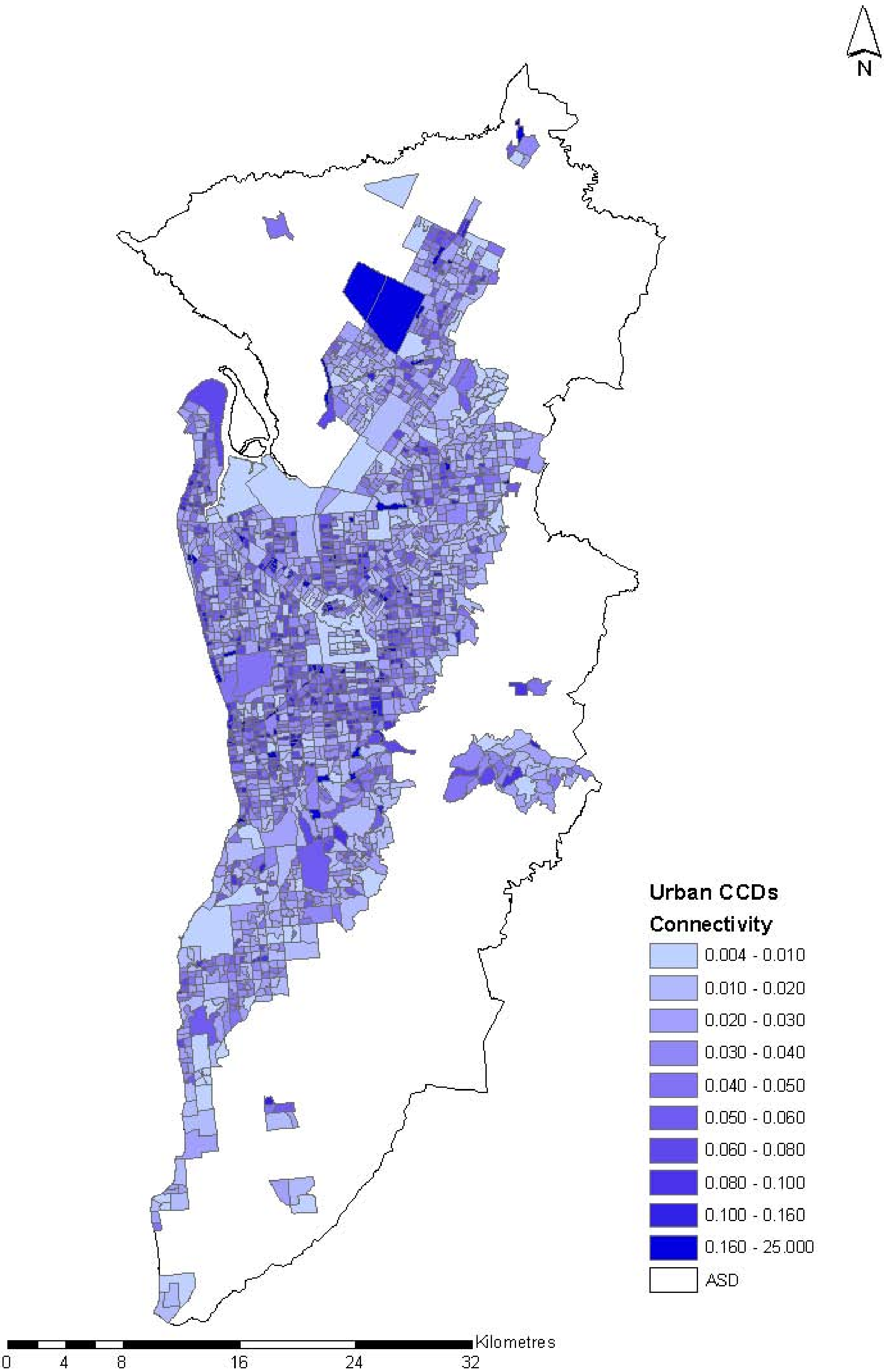


Figure 4.12: Gamma Index per CCD, ASD.

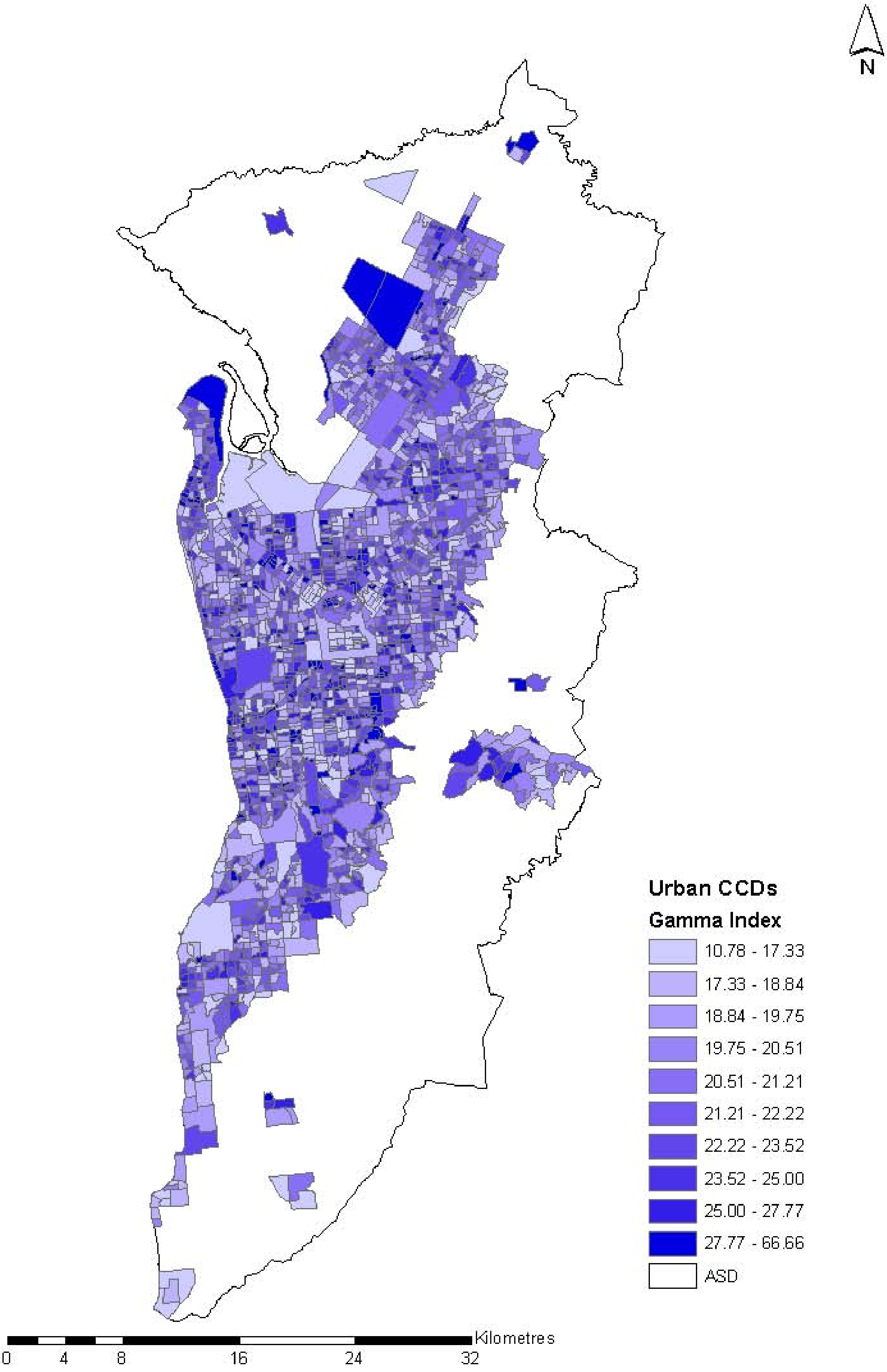
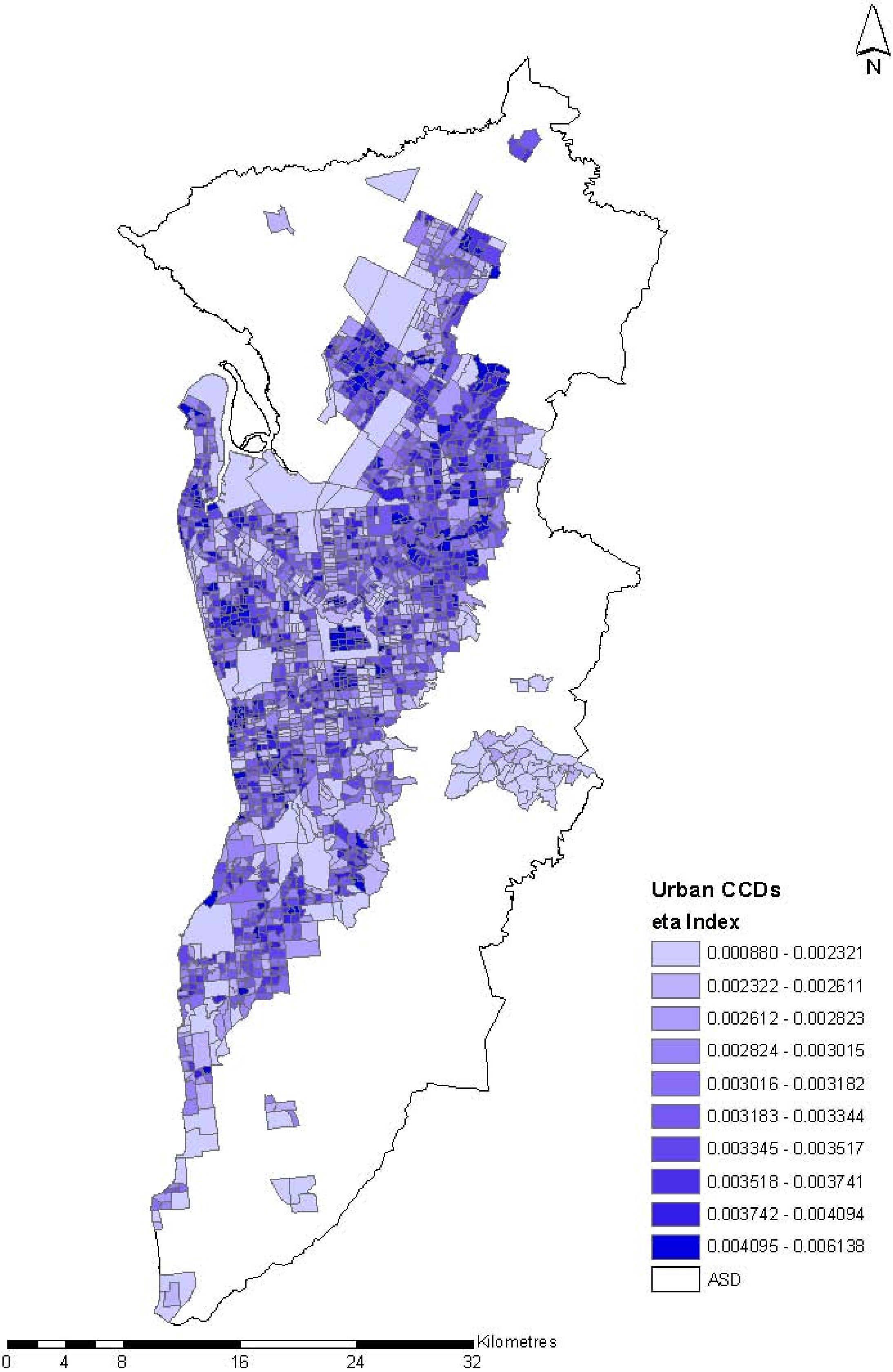


Figure 4.13: Eta Index per CCD, ASD.

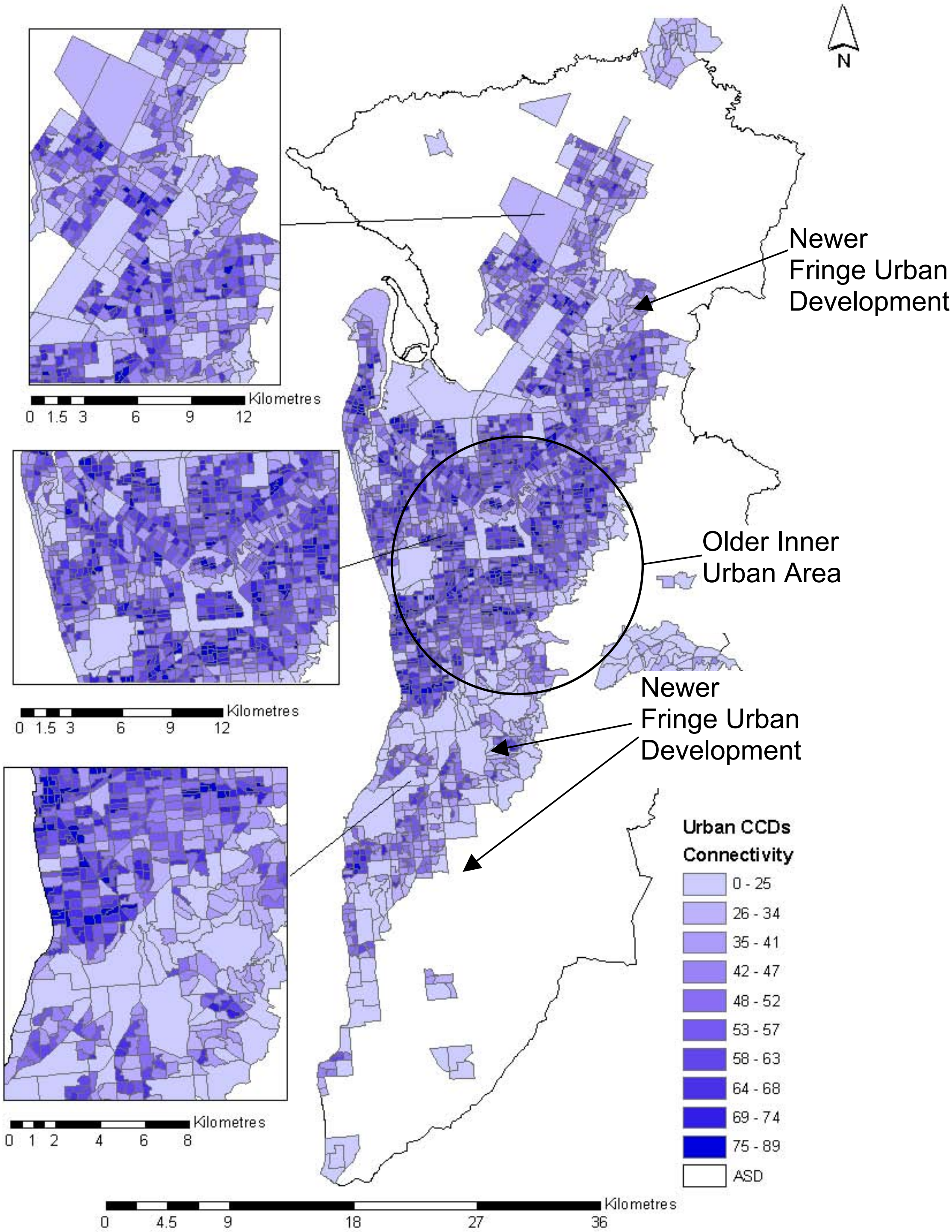


The measures presented above are combined to produce the connectivity element of the walk index. As stated in Chapter 3, each of the calculated measures is ranked in deciles and recoded to 1 to 10, with 1 representing the lowest value for each measure and 10 the highest value. The only variation to this is the cul-de-sac measure where a CCD with a higher number of cul-de-sacs is coded 1 and a low number is coded 10. This measure is to reflect the negative impact cul-de-sacs have on connectivity and will ensure the CCDs with fewer cul-de-sacs score higher in the overall ranking. In total, there are nine measures used to represent connectivity and these are:

- Intersection density (>2 directions of travel);
- Direction density (>2 directions of travel);
- Cul-de-sac density;
- Street density;
- Route density;
- Length density;
- Connectivty;
- Gamma Index; and
- Eta Index.

Consequently, the connectivity score will be between 9 and 90, where 9 represents a CCD with low connectivity and 90 a CCD with good connectivity. The connectivity index is presented in Figure 4.14. The results show that the inner area of the ASD does have higher levels of connectivity than the newer fringe areas. The predominantly grid based pattern in the older areas represents a more connected network and this is reflected in the results. The changing planning paradigms, especially the curvilinear streets with cul-de-sacs are less connected and this is also reflected in the results (Figure 4.14).

Figure 4.14: Connectivity Index per CCD, ASD.



4.2 Measures of Proximity

Proximity is a set of variables, which will measure the relationships within CCDs to highlight those areas that are densely or sparsely populated, have local access to a range of activities, and local retail opportunity. As the focus of this research is a measure of walkability, local access within a reasonable walk distance is an important outcome and these measures aim to highlight areas with good local opportunity. The proximity measures in this section are dwelling density, land use mix and a retail ratio.

4.2.1 Measures of Proximity: Dwelling density

Dwelling density is presented in two ways, first as a gross density or total dwelling in each CCD by the CCD area and second as a net dwelling density or total dwellings by the net of dwelling land per CCD. This is done to look for differences between the two measures, as net dwelling land is not always available or easily accessed and therefore if gross density provides a similar outcome then this more simple measure will be more readily calculated by other researchers applying this methodology to other Australian cities. Gross dwelling density and net dwelling density are displayed in Figures 4.15 and 4.16. The net measure is a more appropriate representation of dwelling density than the gross measure. It is clear from Figures 4.15 and 4.16 that many CCDs change their decile class and therefore would understate CCD dwelling density.

Figure 4.15: Gross Dwelling Density per CCD, ASD.

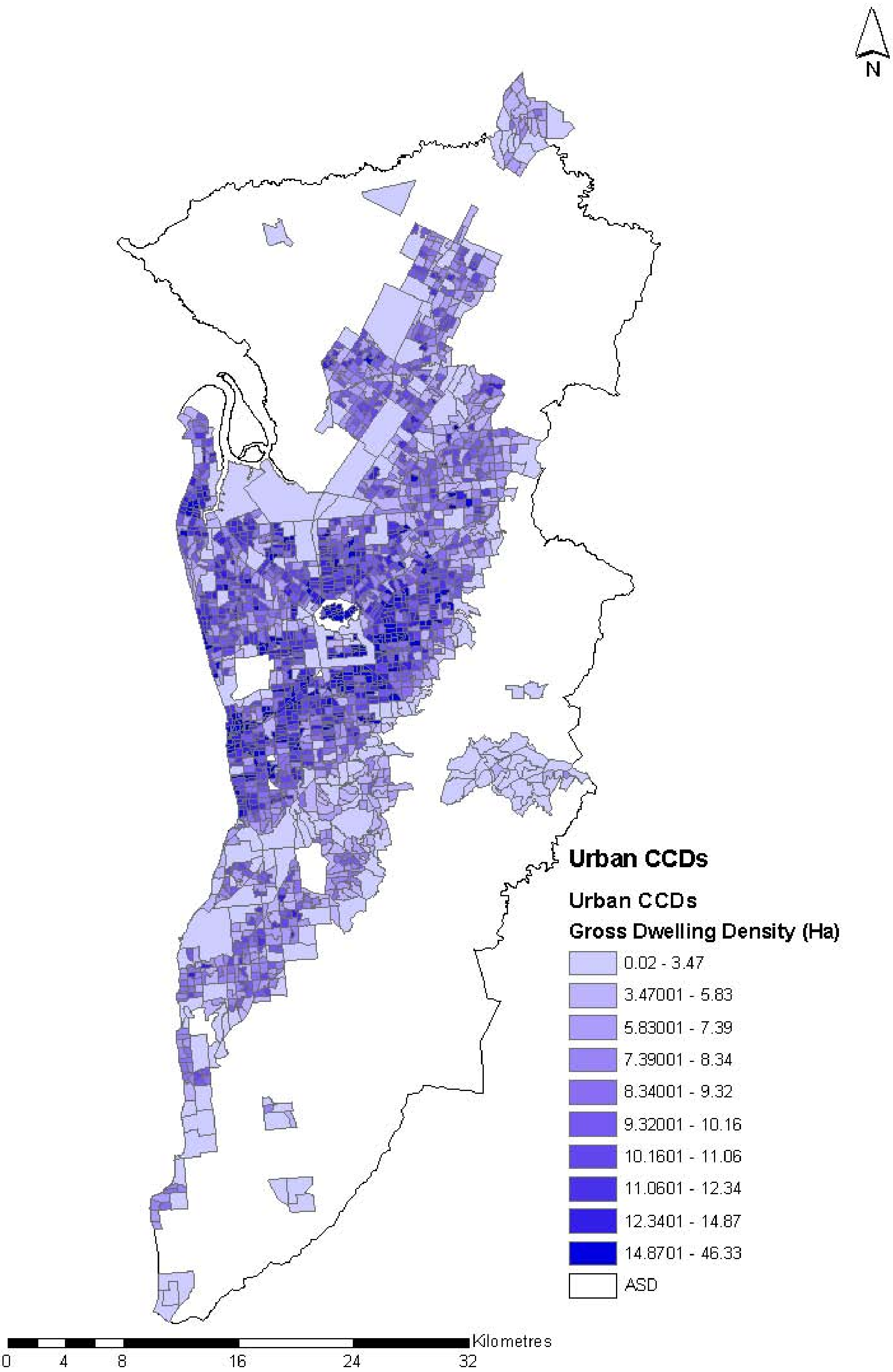
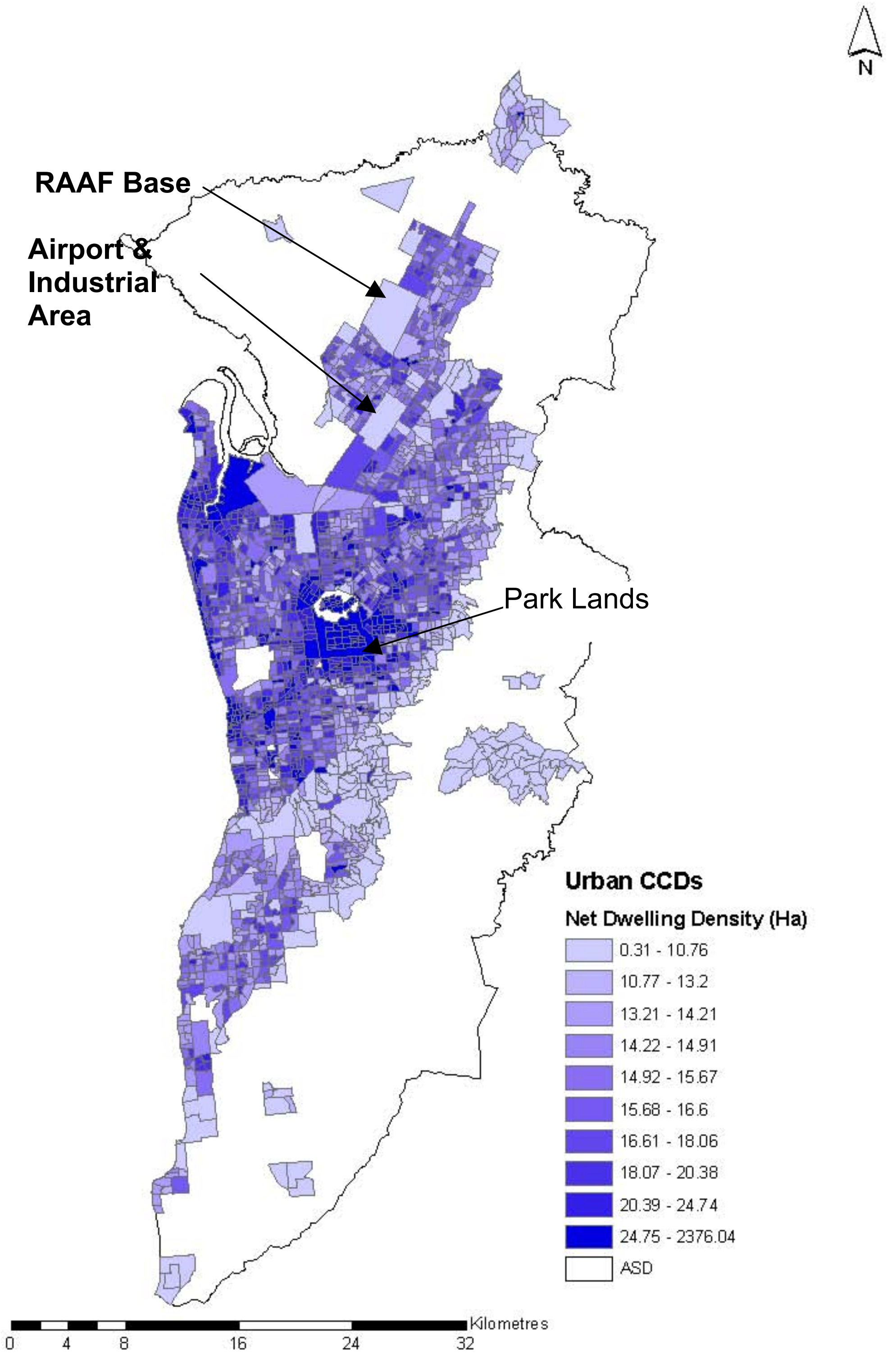


Figure 4.16: Net Dwelling Density per CCD, ASD.



However, it is important to make note of the impact CCD design can play when calculating an index based upon the CCD and more importantly the CCD area. As described in the previous chapter, the CCD is designed to provide a workload for a census collector and in urban areas, approximately 300 dwellings. For those CCDs, which are basically residential, the density will be higher than those CCDs that include other land uses and therefore are much larger in area as part of the design rule of including 300 dwellings. A number of these CCDs are labeled in Figure 4.16 to highlight the differences between the CCD based gross measure and the net residential measure. While these are the larger more visible examples, there are many smaller CCDs, which contain mixed land uses that are more prone to change deciles class from the gross to net measure. The CCDs that change deciles are shown in Table 4.4 and Figures 4.17 and 4.18.

Table 4.4: Decile Change by CCD, Gross to Net Dwelling Density

-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9
2	59	141	289	423	556	202	152	89	63	40	25	10	18	9
0.10	2.84	6.79	13.91	20.36	26.76	9.72	7.31	4.28	3.03	1.92	1.20	0.48	0.87	0.43

Figure 4.17: Decile Class Change, Gross to Net Dwelling Density.

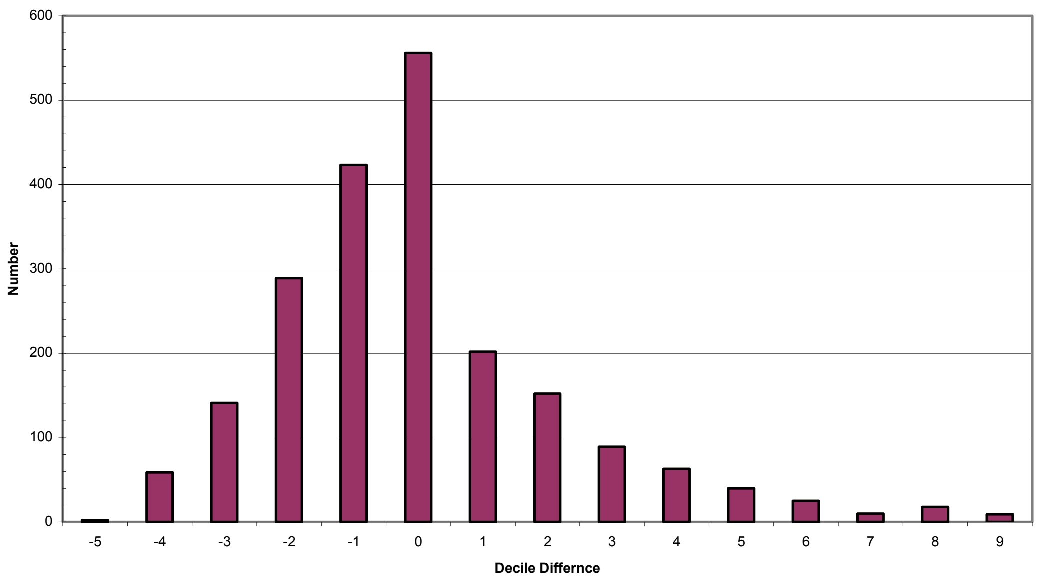
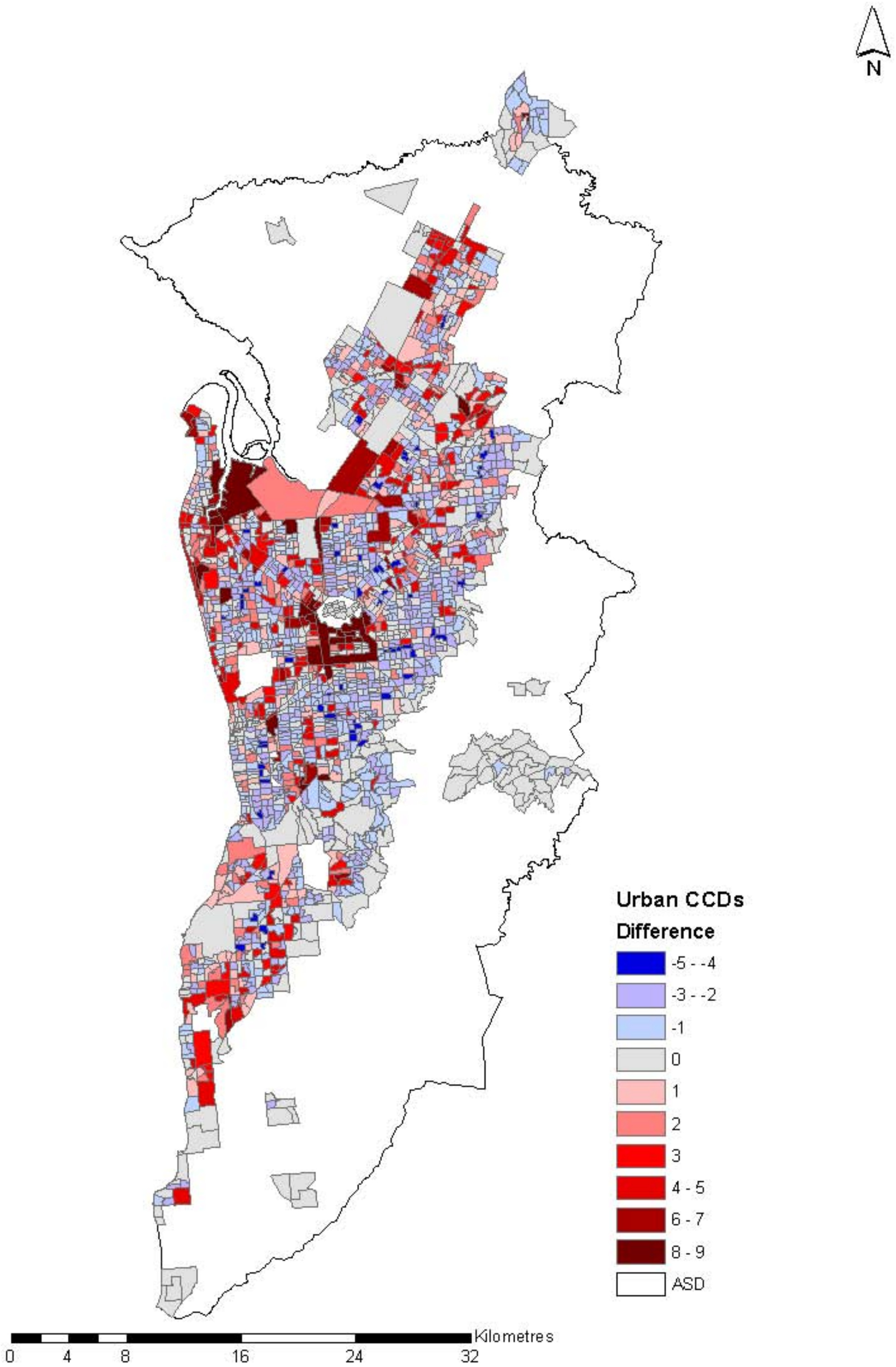


Figure 4.18: Decile Class Change, Gross to Net Dwelling Density, ASD.



It is interesting to note that the majority of CCDs that increase decile classes are in the fringe area whereas the majority of CCDs that decrease decile classes are in the older inner areas. While some CCDs change by many decile classes, most CCDs do not change or move by one decile class (57%) and a further 20% move by two classes (Figure 4.17 and Table 4.4). This is most likely a function of the larger CCDs in the less densely developed newer urban housing in the fringe areas and the smaller more compact CCDs in the older inner urban areas. Consequently, the net dwelling density measure is preferred to the gross measure as it is the more useful measure for comparing densities across large diverse urban areas.

4.2.2 Measures of Proximity: Land Use

A varied land use within a CCD is used as a measure of opportunity for walking behavior. To represent the complexity of different land uses within a CCD, entropy and the Simpson indices of diversity are used. These indices are described in more detail in Chapter 3.

The aim of the walk index developed in this thesis is to characterise CCDs using environmental attributes as either walkable or not walkable. Land use is one of the more important environmental characteristics because a mix of land uses provides residents with opportunities for walking trips to different areas, such as retailing or open space. Older inner urban areas are frequently a more diverse mix of land uses as early Australian urban development occurred without zoning control and without the private automobile, most land uses, such as shopping and industry were located proximal to the resident workforce. With the increase of automobile use and the advent of town planning the older style urban areas were rejected for more homogenous urban developments. The two indices are shown in Figures 4.19 and 4.20.

Figure 4.19: Entropy Score deciles, by CCD, ASD.

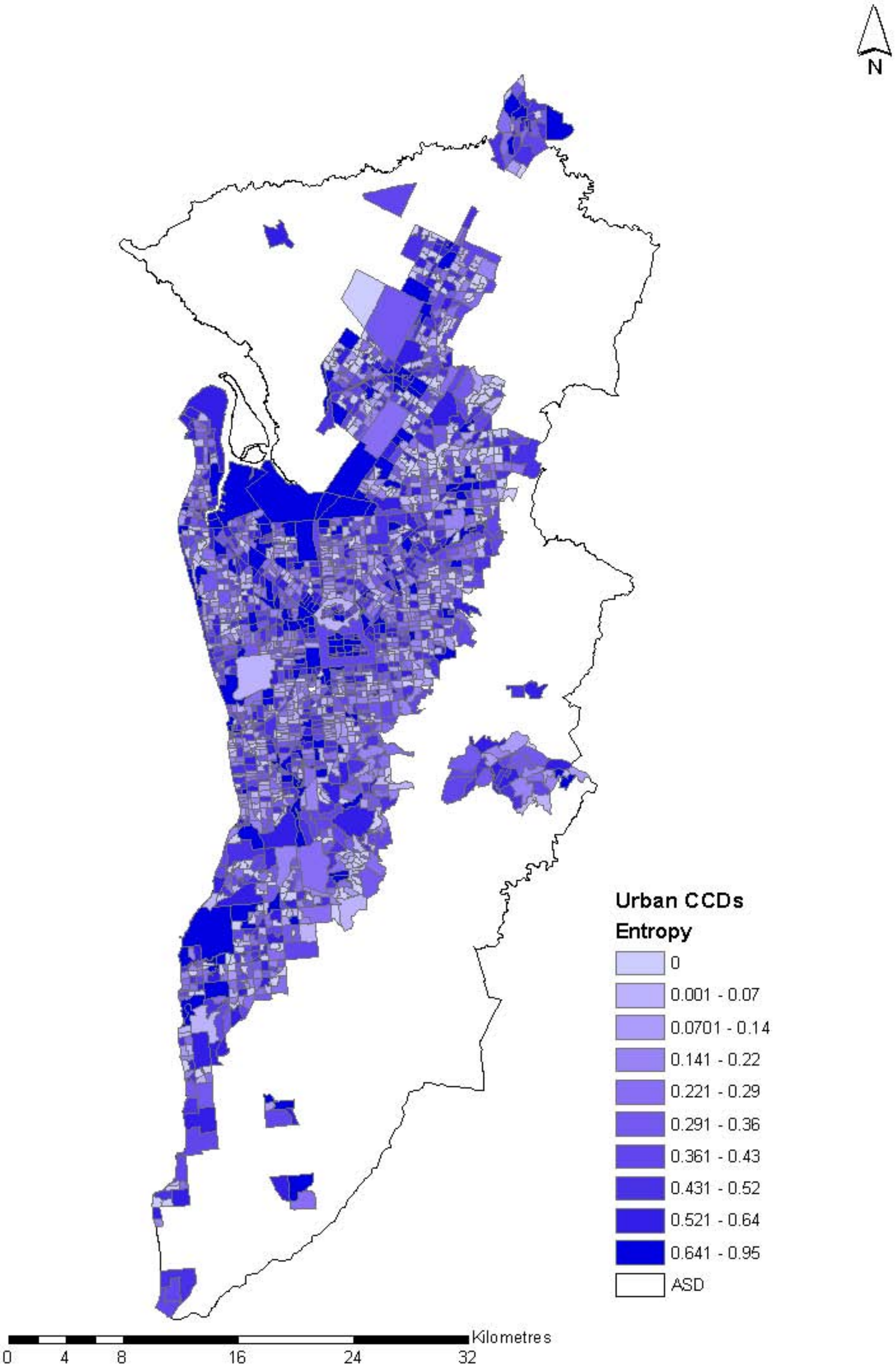
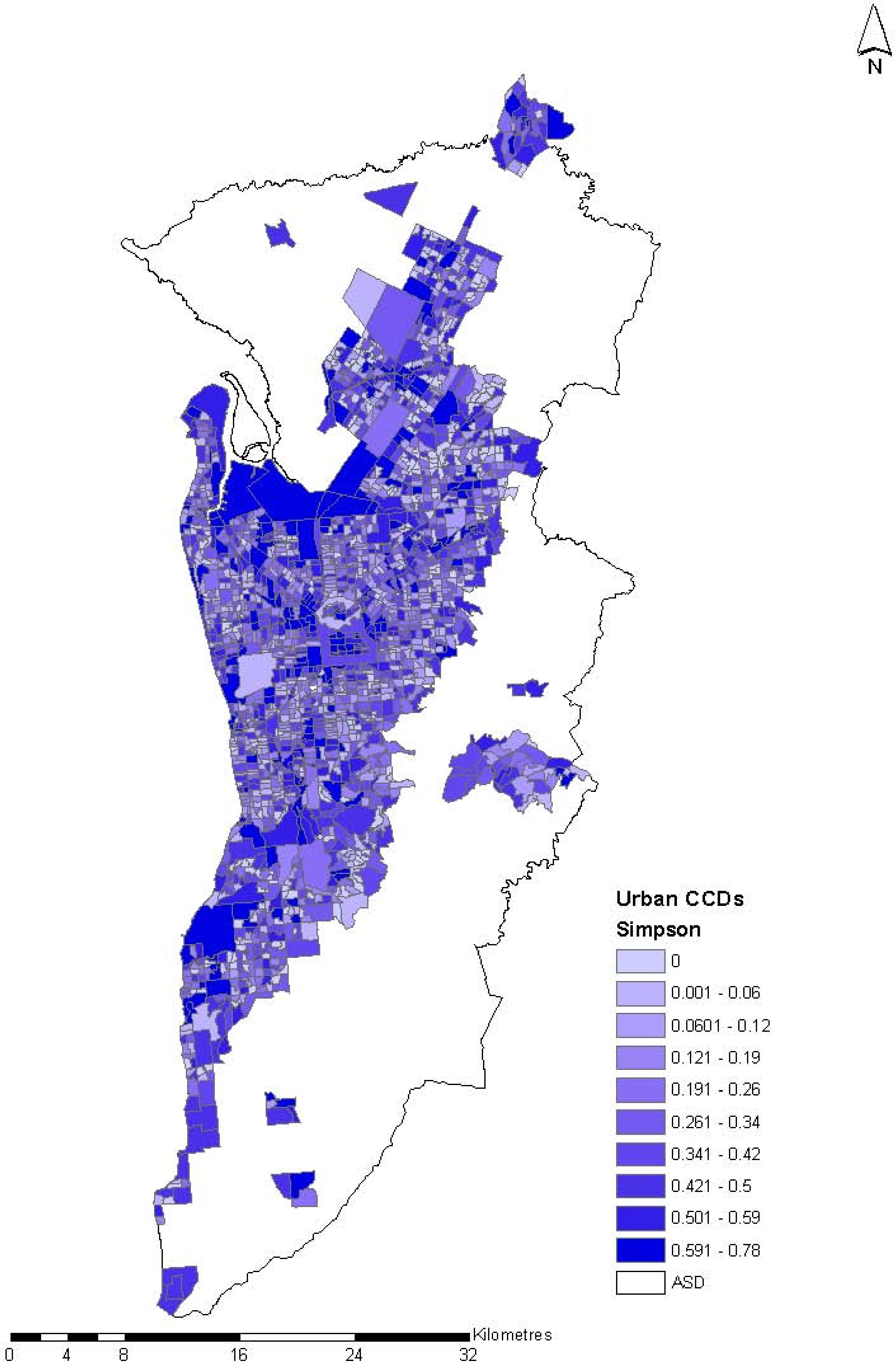


Figure 4.20: Simpson Score deciles, by CCD, ASD.

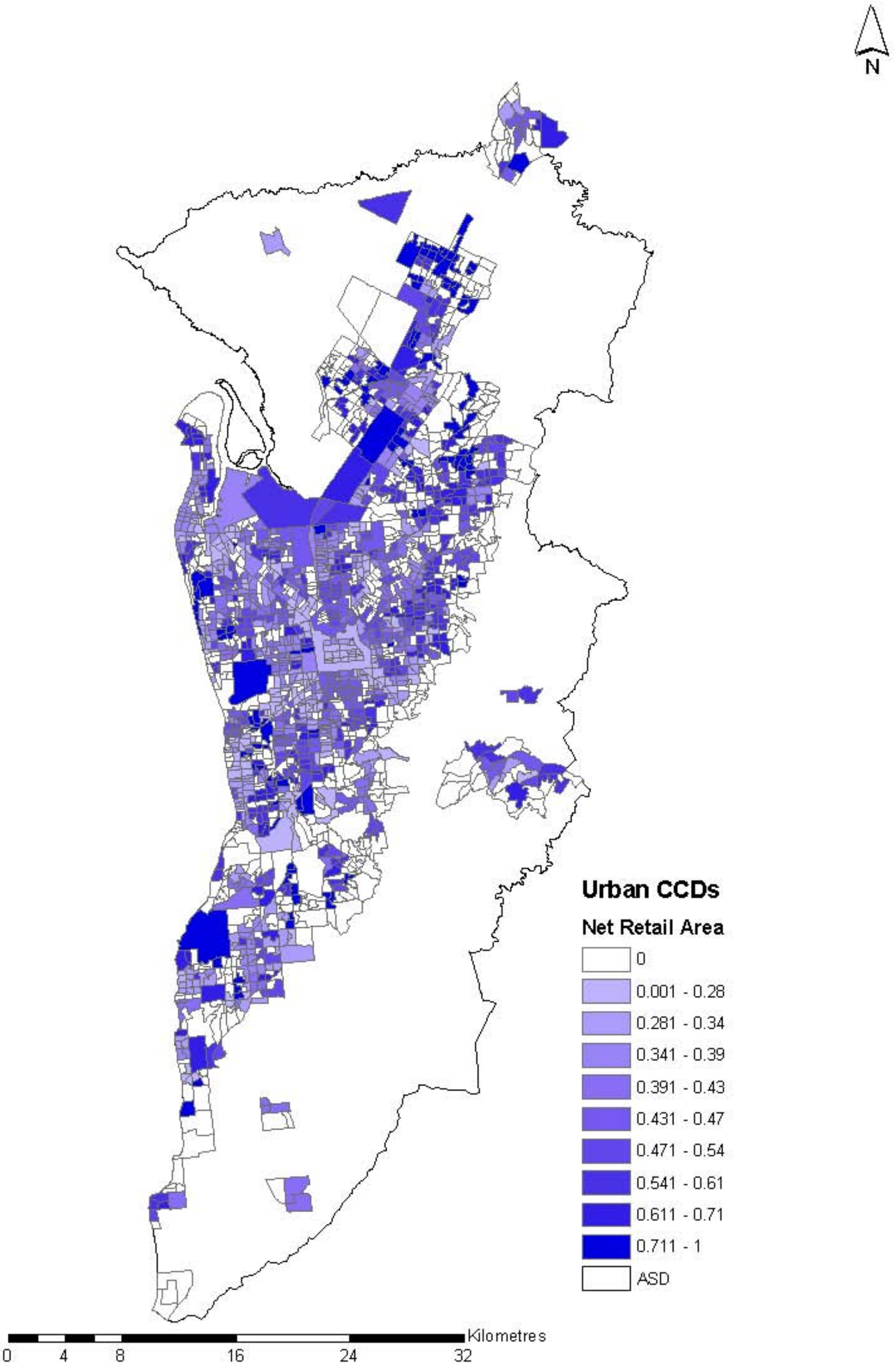


These indices highlight the CCD size issue outlined above, with the larger CCDs with more potential for different land uses scoring higher entropy and Simpson scores. The two scores produce very similar results and consequently either index could be used to quantify the mix of land use. Plane and Rogerson (1994) describe both indices and through worked examples calculate slightly different results which suggest that the Simpson measure reflected a better result for measuring diversity in their worked example. As an indication of the differences, the decile classes for each index was compared and 1520 or 73 percent are the same class, 549 or 26 percent are one class different and less than half of one percent are two classes different (9). Consequently, either measure will suffice for this research, but as an aim here was to work towards comparability with the US study, the entropy score is used to characterise land use diversity.

4.2.3 Measures of Proximity: Retail

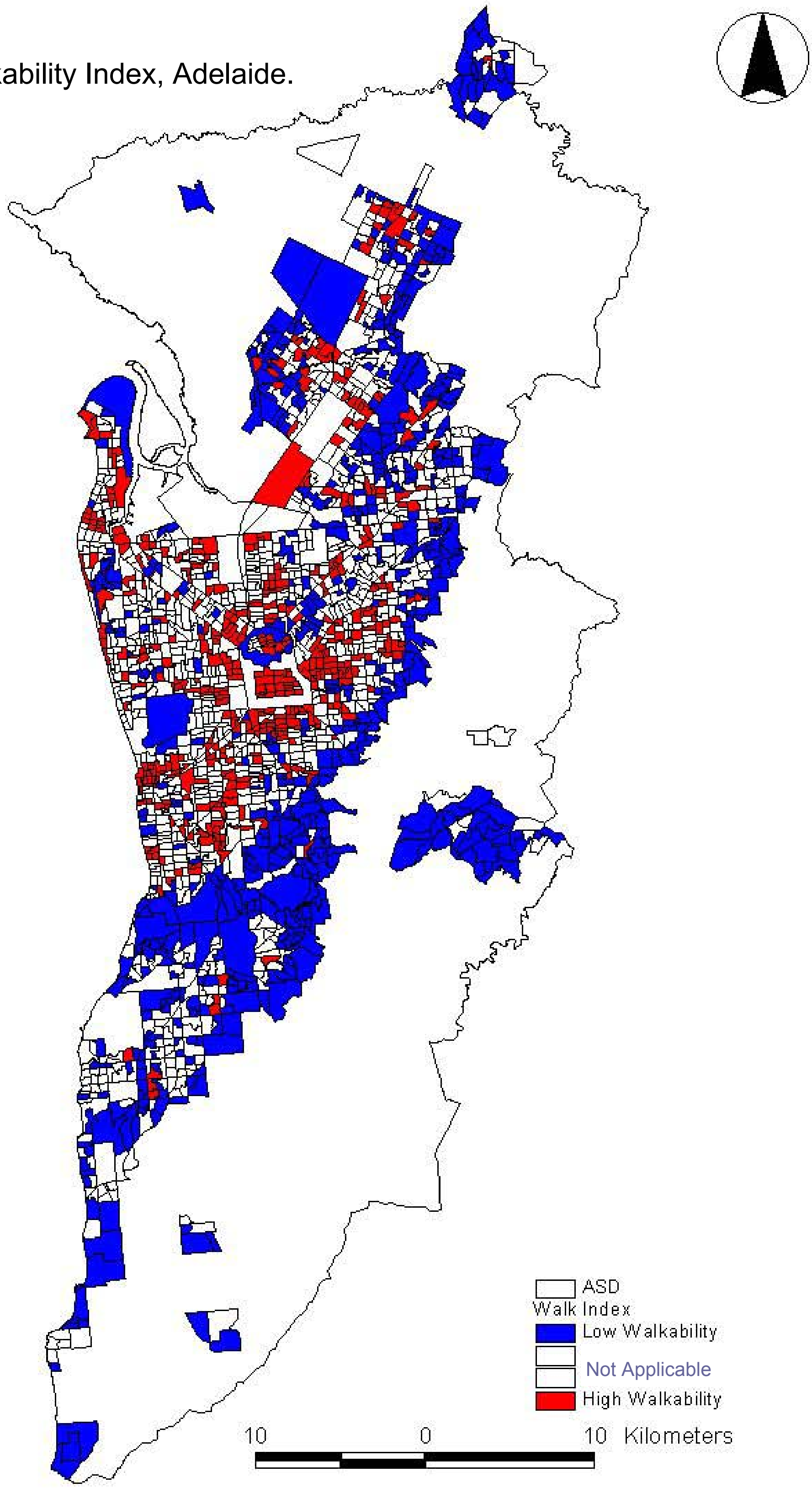
The final proximity measure is an indication of the access to, and walk friendliness, of local retail centres. This measure results in higher values for those CCDs with retail centres, but as walk trips to local shops are more common (Handy et al. 2002, Handy 1996), this measure is important in highlighting those CCDs where walk trips to the shops are most likely to occur. The net retail area decile values are displayed in Figure 4.21. Those CCDS without retail (zero values) are visualized using white. Again, the influence of the planning design paradigm is evident in the results. The inner older areas of Adelaide are more represented with retail opportunity than the newer fringe urban areas.

Figure 4.21: Net Retail Area Deciles, by CCD, ASD.



With the connectivity and proximity measures calculated for CCDs, the walk index can be constructed from these measures and is presented in Figure 4.22.

Figure 4.22: Walkability Index, Adelaide.



The walk index is calculated by summing the decile score for each factor, without weighting. The literature review did not reveal any use or support for weighting, and Ewing, Pendall and Chen (2003) concluded in their Measuring Urban Sprawl Report that,

> *"… we could think of no rationale for differential weights…. Thus they [measures] were simply summed." (p.25, 26)*

The walkability index highlights the older inner areas as more walking supportive and the fringe newer developed areas as less supportive of walking. This version is the basic walking index, other variants of the measures are possible, such as weighted versions or versions with one element removed. Some of the myriad of possible combinations of variables was processed, but as an objective of this study was to match as closely as possible with the US study, only the standard version is provided here. Testing the variables and construction of the walkability index with actual walking behaviour will require the results of the survey to test for correlations between walking behaviour and individual variables and groupings of variables and although this is not a part of this study it is part of the next phase of the PLACE research.

4.3 Validating the Walkability Index

The actual validation of the walkability as stated above, is part of the larger PLACE study and involves analysis of the survey results in relation to the overall walk index and the elements of the walkability index construction. In the absence of the survey based validation, field validation was conducted in various parts of Adelaide to check the performance of the walkability index and determine how well the method worked as a means of classifying areas on the basis of environmental attributes which support walking behaviour. Several days were spent in the field by the PLACE team visiting areas identified as highly walkable (4th quartile), areas of low walkability (1st quartile) and areas in the 2nd and 3rd quartiles.

In the field, most areas' physical characteristics accorded with the classification of walkability and therefore it was concluded that the methodology does return a reliable means of identifying areas based upon the input characteristics of dwelling data, land use and zoning, intersection data and net retail area. A few notable anomalies were observed. For example, a large development in the North East of Adelaide, Golden Grove is characterised by a street pattern which is curvilinear, has many cul-de-sacs, relatively low land use mix and a net retail area which reflects the car dominance of the shopping centres. However, the housing estate has a major pedestrian network which links the housing, schools, recreation areas and shopping and this is not reflected in its low walkability index. Another older inner area, Dulwich, has an older grid road pattern, wide tree lined streets, good walking access to shops and recreation, but does not score in the 4th quartile. In these cases, the walkability index is biased by low intersection density and poor land use mix in Golden Grove and low dwelling density and low land use mix in Dulwich. However, the index was returning values, which reflected the environmental characteristics and therefore did provide a means for identifying areas to target for a questionnaire to determine if there were influences on physical activity.

The walkability index presented in this section is built upon the knowledge of health and environmental influences of physical activity and the urban and town planning professions research work to date. Clearly, the actual index draws heavily from the transport and urban planning literature in the choice of variables used to construct the walkability index for Adelaide. There were two major issues influencing the walkability index, the data availability and the objective of providing a comparable index to work recently completed in the US (Frank et al 2005). The twin themes of proximity and connectivity occur consistently throughout the planning and transport literature in studies examining the way people in neighbourhoods classified as traditional or automobile dominated travel for work and non-work. The results of the many transport and urban planning studies are provided in Chapter 2 and provide convincing evidence that proximity (density and land use mix) plus connectivity (street network) plus access to retailing are linked with the mode people choose to travel. While the physical health professionals are interested in the environmental influences of physical activity, it is only recently that the vast transport and urban planning literature has started to find it way into public health studies. The walkability index constructed for this study is the result of this recent recognition and represents the collaboration of the health professionals in the construction, delivery and analysis of the walking survey, and geography in the application of GIS to build the spatial index of walkability through the PLACE study.

The success of the walkability index will be tested as the survey results become available and is part of the wider research agenda of the PLACE study. However, based upon the characteristics used to construct the walkability index, the field validation supports the belief that these characteristics can be successfully combined to provide a basis for objectively classifying areas in Australian cities as walking friendly.

CHAPTER 5 DISCUSSION

ISSUES, FUTURE DEVELOPMENTS AND APPLICATIONS OF WALKABILITY-RELATED MEASURES

The use of environmental factors to create an objective characterization of urban areas is supported by the many studies using similar factors from the transportation and urban planning literature (Grant 2004; Schlossberg and Brown 2004; Timmermans 2004; Ewing, Pendall and Chen 2003; Main 2003; Rajamani et al. 2003; Handy and Clifton 2001; Cervero and Kockelman 1997; Kitamura, Mokhtarian and Laidet 1997; McNally and Kulkarni 1997; Cervero and Radisch 1996; Ewing, Haliyur and Page 1996; Handy 1996; Cervero and Gorham 1995; JHK and Associates 1995; Friedman, Gordon and Peers 1994; Handy 1993; EDA Collaboration Inc. n.d.; Morris and Kaufman n.d.). The advantage of working with indices such as the ones constructed in this study is the capacity to identify areas based upon a set of criteria as either high walkable to low walkable. Further refinement and validation of the walkability index can be achieved by using the results of survey respondents physical activity levels and local environment perceptions. Armed with the results from the survey, the environmental factors can be statistically tested for correlation with physical activity levels. Through studies such as this and the wider PLACE project, the design and use of objective measures can be further refined.

There are a number of issues that could influence the design and use of walkability indices such as the one presented in this research. The literature review identified a range of characteristics causally linked with walking behaviours, especially walking for transport, and these characteristics form the basis of the walk index constructed in this thesis. What is clear, is there are many other factors linked with walking behaviour, some identified in the research reviewed for this study and others that warrant further consideration. With GIS, the capacity to capture, store, manipulate and analyse different spatial characteristics is largely untapped in the physical activity and environmental influences of physical activity research.

The four factors applied in this study build from the work of the transport, planning and the health professionals and apply these measures to an Australian city. Data availability will play a large part in determining what can be used to measure walkability, however, as is evident from this study, data are available therefore this index can be constructed for other Australian cities. The limitations of this study, especially the requirement to create an index similar to the US research prevented the use of more detailed factors. As mentioned earlier, density, land use mix, street network connectivity and retail access are all linked in numerous studies with positive walking outcomes. However, while land use mix is clearly important, there is a growing recognition that it may not be enough to capture the degree of mix, but the actual mix of different land uses (Hess, Moudon and Logsdon 2001). This introduces the concept of good land use mix or land use mix that is positively correlated with walking activity and poor land use mix that does not correlate with walking activity. Cerin, Leslie and Owen (2004) have tested the relationship of the four factors used in this walkability index as part of the continuing PLACE analysis and report that the factors correlate positively with walking behaviour, except the land use mix factor. Retail is highly correlated with walking and therefore land use mix that is a healthy mix of residential, retail, recreation is more likely to provide support for walking behaviour than industry, agriculture and recreation. The exact nature of these results is not known as yet as this work is still in the early stages, it does provide some support for the walk index and support the need for more detailed consideration of the factors that go into creating an objective walking index for urban areas.

This is a starting point for further work and the development of walking indices should include other aspects identified in the public health literature, such as the presence of parks and recreation facilities (Wendall-Voss et al. 2004; Pikora et al. 2002; Lee et al. 2002; Sallis et al. 1997); the presence, condition and continuity of footpaths (Main 2003; Handy et al. 2002; Stonor, de Arruda Campos and Smith 2002; Cervero and Kockelman 1997; Sallis et al. 1997; Parsons Brinckerhoff Quade and Douglas Inc. 1993; Pedestrian and Bicycle information Center n.d.); observational disorder (Caughy, O'Campo and Patterson 2001); aesthetics (Saelens et al. 2002; Ball et al. 2001; Pedestrian and Bicycle information Center n.d.); safety (Barton 2004; Saelens et al. 2002); accessibility or distances to facilities (Barton 2004; Pikora et al. 2002; Giles-Corti and Donovon 2001); transit accessibility (Kitamura, Mokhtarian and Laidet 1997); neighbourhood playgrounds, fast food restaurants, and crime (Burdette and Whitaker 2004, Reidpath et al. 2002); topography (Parsons Brinckerhoff Quade and Douglas Inc. 1993); and the presence of walking and cycling trails; footpath width, gradient, design and proximity to traffic, pedestrian crossings location and design, pedestrian traffic volumes, time of day, day of the week, street lighting, (Stonor, de Arruda Campos and Smith 2002); walking permeability indicator or street distance/Euclidian distance (Alan 2001); and barriers (Handy and Clifton 2001).

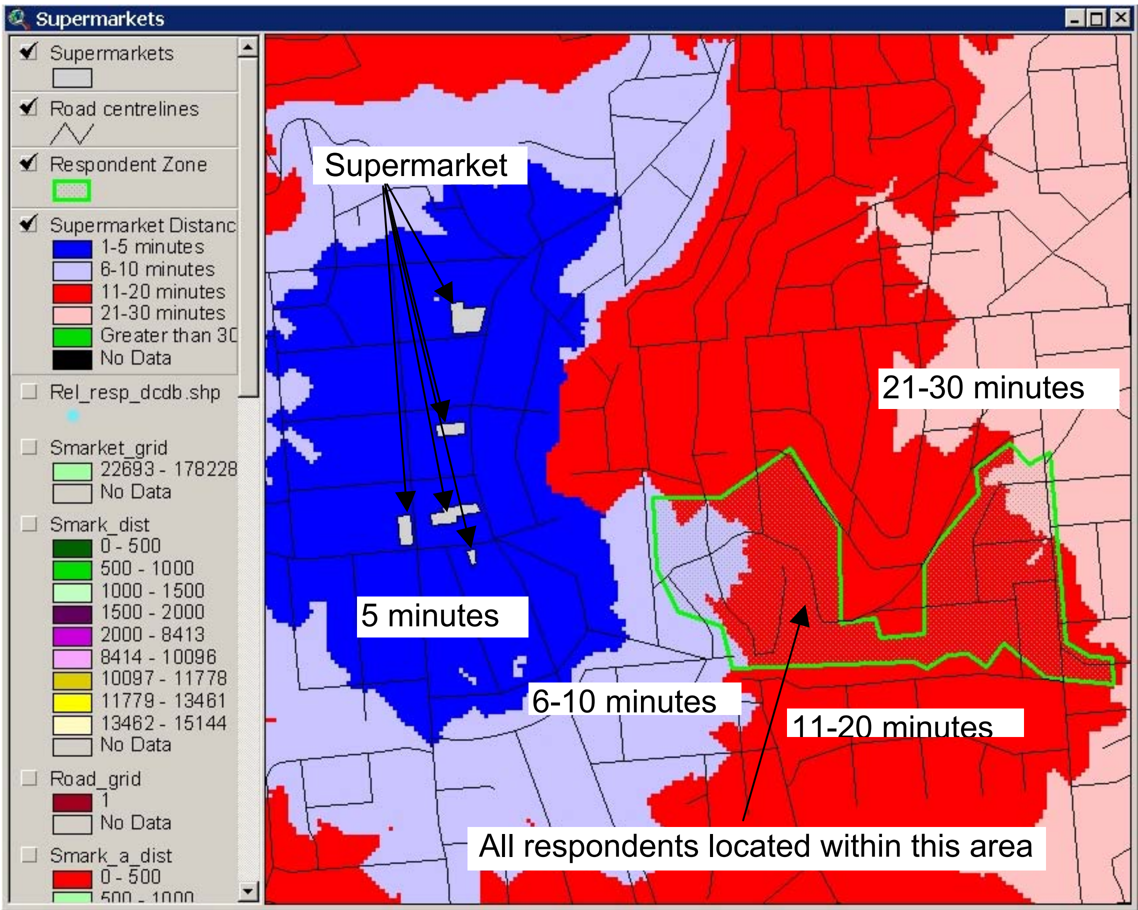
Indeed, a more detailed and informed measure of walkability index could include some or all of these characteristics that independently exert an influence on walkability. Aesthetics could be measured in a number of ways including, a greenness index or vegetation density, distances to a range of facilities or services including public transit stops will provide a measure of access, natural barriers could include rivers, valleys or major roads, traffic volumes, crime and safety could be sourced from crime and safety data. The width of roads, presence and condition of footpaths, street lighting, trails, wide verges, linear parks along water courses, coastal parks and reserves will be influential in whether people will be willing to engage in walking. Access to substantial public parks and reserves of a substantial size, coastal beaches, national parks and major recreational destinations are also important. The section above lists a range of other factors that are worthy of consideration and depending upon data availability should be incorporated into a later version of walking indices. It is important to consider the costs associated with some of the data items listed above, as many of these data would require detailed data collection and are not readily available for all areas. In addition, validation and survey results are also required to test whether these characteristics are linked with walking behaviours and the extent a more detailed walking index differs from the less detailed index calculated in this study. Perception versus reality is also important, especially for items such as safety. The perception of safety will differ for different age groups, gender or different levels of physical ability. Consequently, the calculation of a walkability index needs to have a clear aim that can be achieved. It is in this way that the present PLACE study can add to the body of knowledge by offering a walk index and as the project progresses the survey results to test the factors used to build the index.

As well as additional factors, distance based measures are also worthy of consideration. Distances to major services, such as a local shop, post office, public transport, local park and regional park and facilities are also likely to influence choices to make walking trips in local neighbourhoods. The extent to which a local environment is safe may also have an influence on the extent to which people will be willing to walk. This refers to both the density of motorised traffic that has to be encountered in the course of walking and exposure to the risk of crime. Crime and safety pose more of a challenge than many of the factors listed in this study due to the issue of perception of safety and measured levels of safety. As stated above these issues will also differ for different groups in society and while a measure can be applied, this factor more so than the many others listed in this study will benefit from survey results to measure its influence. However, a statistical measure of safety applied for an area and used in a walkability index will not necessarily alter or reflect the perception of safety for living in the area. While this issue will also impact on some of the other factors used in this version of a walkability index, the factor choice was limited to readily available quantified measures. The use of less complex factors is an attempt to provide a measure that can be applied principally across other large cities in Australia, but also in other countries with comparable data sets.

A further development in the use of the walkability index in public health, transport and planning research is to use these characteristics at the individual residence level. Many of the elements involved in the derivation of the index of walkability are applicable at an individual residence level and it would be desirable to calculate the index for each individual residence. This would require identifying the relevant boundaries around each residential location, within which the measures of relevant attributes can be derived and an individual walkability score calculated. This would allow a surface of walkability to be derived and aggregated to any spatial level to protect confidentiality and for further analysis. A measure that includes the additional elements and is built upon the actual residential location will provide a more robust measure built upon a greater range of inputs and will be more flexible spatially as it can be aggregated to a multitude of existing spatial units or custom areas.

As part of the validation of the survey instrument for the PLACE study, two locations were chosen to test the survey reliability, a high and low walkable area identified using the walkability index detailed in this thesis. For details of the validation study, see Leslie et al. 2005. To test the perceptions of time distance by the respondents to actual measured distance using GIS, spatial access surfaces for a range of services were generated (Coffee et al. 2003) (Figure 5.1).

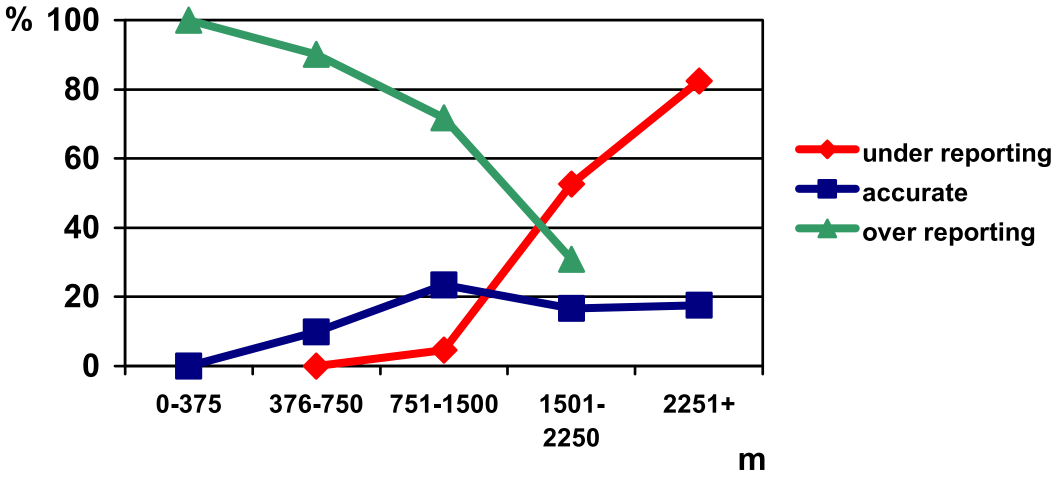
Figure 5.1: Time-Distance to Supermarket, Hawthorndene.



Source: Coffee et al. (2003).

The surface in Figure 5.1 displays the time-distance calculation for access to the closest supermarket for respondents in a low walkable area in southeastern Adelaide. Surfaces such as these use the road network to measure distance, based upon this surface, the distance to the closest facility can be calculated for any dwelling location, in this case for the Hawthorndene respondents. Similar surfaces to this were calculated for access to the closest shop, post office, café, park, bus stop, library and supermarket. It was clear that people did not accurately perceive distance to facilities, especially facilities nearby (Figure 5.2)

Figure 5.2: Percentage of respondents under-, over- and accurately reporting distances within different distance categories



Source: Coffee et al. (2003).

It is clear from Figure 5.2, that the perception of time-distance is very poorly reported, with all the respondents (n-100) over reporting facilities within 375 metres and 80% under-reporting facilities 1500 metres or 2251 metres or more from their homes (Coffee et al. 2003). Notwithstanding the issues of perception versus GIS measured distance, the spatial surface method provides a more detailed capacity for measuring access based factors and can provide data for individual dwelling locations or distance means can be calculated for any aggregate spatial unit (such as the CCD, suburb, postcodes etc). With aggregated measures and spatial surface measures, a more detailed index of walkability can be constructed that reflects aggregate environmental influences as well as individual access measures.

An additional benefit of the spatial surfaces method is that it can remove the bias introduced using administrative spatial boundaries such as the CCD. As stated previously, the CCD is an administrative unit designed by the Australian Bureau of Statistics to manage the collection of the census every five years. The design basis of the CCD is a two-week workload for a collector to deliver and collect census forms. A workload in urban areas is approximately 250-300 households and the CCDs are designed to contain that approximate number of dwellings. In less urbanised areas the number of dwellings decreases and the CCD area increases. The CCD does not contain any temporal consistency in areas, which are growing or declining and therefore a CCD may be split or merged from one census to the next dependent upon what is happening to the population.

When working with aggregate spatial units such as the CCD it is not always clear that the units represent areas that are socially or morphologically similar as the CCD boundary is built from road centrelines. Dwellings on opposite sides of the street usually have more in common than dwellings over the back fence and consequently, the spatial unit may skew the outcome of any analysis, including the walkability index. The impact of aggregate spatial units is typically termed the modifiable unit area problem and should be considered as one of the issues inherent in the design of an objective walkability index.

Another issue to be considered with the CCD or the use of any existing spatial unit is the problem of building the measures for retail for example when the subject CCD does not contain any retail land use. The adjoining CCD does contain retail and for the residents near that boundary of the CCDs will not recognise the CCD as a boundary but will interact with the retailing. One possible solution to this issue is to build the data set for each unit (the CCD) but take data for a kilometre buffer from the centre of each spatial unit. In this way, the value for each CCD will reflect the wider environment that residents will see as local space and not bias the index as much as the CCD only data set.

Testing the different measures, incorporating access measures and modifying the collection routines to incorporate data for the wider buffer area are all areas that are promising future research directions to further the development of objective walkability indices using Australian data.

CHAPTER 6 CONCLUSION

Western countries are facing major health issues related to overweight, obesity and the lack of physical activity (CDC 2004; ABS 2003; AIHW 2003; Cameron et al. 2003; Mokdad et al. 2003; ABS 2002; AIHW 2003; AIHW 2002; Contaldo and Pasanisi 2003; Flegal et al. 2002; Mokdad et al. 2001; Mokdad et al. 1999; WHO 1998; ABS 1998 and ABS 1995). Obesity is a serious problem that costs billions in direct health budgets and many additional millions in indirect costs (Finkelstein, Fiebelkorn, and Wang 2003; Wolf and Colditz 1998; Wolf 1998). It has been identified that moderate physical activity such as walking several times per week can reduce the health burden attributed to the obesity-overweight epidemic (Brown 2004; Bauman et al. 2002; Giles-Corti and Donovon 2001;Troped et al. 2001; Owen et al. 2000; US Surgeon General's Report 1996) and therefore it is crucial to understand what supports or hampers walking behaviour (Wendel-Vos et al. 2004; Humpel et al. 2002; Pikora et al. 2002; Ball et al. 2001; Brownson et al.2001; Giles-Corti and Donovon 2001; Owen et al. 2000; Sallis, Bauman and Pratt 1998; Sallis et al. 1997).

Aspects of the environment have been positively correlated with walking, especially higher densities, mixed land uses, good street connectivity and access to retailing in physical activity, transport and urban planning studies. An objective walkability index using these characteristics is presented in this study constructed from Australian data as part of the process of developing and testing the influences of the environment on walking activity. GIS is a useful tool for capturing, storing and managing the process of creating a walkability index and is used in the study as the basic tool for constructing the walk index. The walkability index presented in this study supports the findings of earlier work with older more compact well connected areas generally scoring higher walk index values than the newer less dense, segregated land use developments so popular in Australia (and overseas) post world war two and through to the present.

The walkability index is supported by field validation and early work by Cerin, Leslie and Owen (2004) however, more detailed analysis of the PLACE survey work is required before concluding that the index is a useful addition to the characterisation of how the environment may impact upon physical activity.

More work is required to refine the actual measures underlying the broad factors especially the land use mix factor, to better reflect good land use mix and bad land use mix from a walking perspective. The inclusion of additional factors and spatial unit selection can be important and this warrants further work especially the use of buffering for aggregate spatial units to include the influence of adjacent areas in the walkability index value for each CCD.

An area worthy of pursuit is the construction of individual level access surfaces for a range of services, including local shop, post office, bus and train stops, parks (local and regional) to list a few. The combination of the aggregate measures plus individual level access surface measures is an exciting prospect for including factors that have been identified in both the public health literature and the transport and urban planning literature. The work presented in this study is the first stage in progressing objective measures in Australia with the potential, due to the design rules applied to this version of the walkability index, to be compared with similar work overseas.