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Spatial and socioeconomic inequities in liveability in Australia's 21 largest cities: Does city size matter?

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A B S T R A C T

Spatial and area-level socioeconomic variation in urban liveability (access to social infrastructure, public transport, open space, healthy food choices, local employment, street connectivity, dwelling density, and housing affordability) was examined and mapped across 39,967 residential statistical areas in Australia's *metropolitan* (n = 7) and largest *regional* cities (n = 14). Urban liveability varied spatially, with inner-city areas more liveable than outer suburbs. Disadvantaged areas in larger metropolitan cities were less liveable than advantaged areas, but this pattern was reversed in smaller cities. Local data could inform policies to redress inequities, including those designed to avoid disadvantage being suburbanised as cities grow and gentrify.

1. Introduction

To leave no-one behind is a 'central, transformative purpose' of the United Nation's Sustainable Development Goals (SDG) (United Nations General Assembly, 2015) and the UN Habitat's New Urban Agenda (United Nations, 2016; United Nations System Chief Executives Board for Coordination, 2017). Yet achieving this ambition is a major challenge, given reports showing that global inequities are rising (Oxfam, 2016), and that those most vulnerable are more impacted by the COVID-19 pandemic (Oxfam, 2016) and climate change (Watts and al, 2019).

Where people 'live, learn, work and play' (World Health Organization and Commission on the Social Determinants of Health, 2008) has a profound impact on their health and wellbeing (World Health Organization and UN Habitat, 2010; World Health Organization and UN Habitat, 2016; Giles-Corti et al., 2016). In a rapidly urbanising world, urban and transport planning must be transformed to improve health, reduce poverty and social inequities, and mitigate and adapt to climate change risk (Dora et al., 2015).

Solutions to reduce urban health inequities between socioeconomically advantaged and disadvantaged neighbourhoods lie beyond the health sector (World Health Organization and UN Habitat, 2010). Planning decisions across multiple sectors – urban planning, transport, education, economic development, housing, public open space, health, and community services – reduce or amplify inequities (i.e., systematic, socially produced, modifiable, and unfair inequalities). These decisions determine where and how communities are built, the sustainability of urban development, and levels of access to infrastructure and amenities that support or hinder life-enhancing opportunities, healthy and sustainable lifestyles, and ultimately, quality of life (Giles-Corti et al., 2016).

Achieving the aspiration of leaving no-one behind and reducing health inequities in cities therefore requires cross-sectoral integrated governance, aligned with the World Health Organization (WHO) concept of 'health in all policies' (Newman et al., 2014). Integrated long-term strategic planning is needed to overcome barriers to providing services, resources and opportunities (Giles-Corti et al., 2016) that create the social and economic conditions for good health and wellbeing (World Health Organization and UN Habitat, 2010; World Health Organisation, 2016; World Health Organization, 2016). Effective policies to combat the root causes of urban inequities require research evidence on the nature and extent of inequities in access to amenities and infrastructure within cities; and the interventions required to address these disparities (United Nations System Chief Executives Board for Coordination, 2017). National averages of access to infrastructure and amenities - often featured in global indicator frameworks - mask

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inequities *between* cities, while city-wide averages mask inequities *within* cities (World Health Organization and UN Habitat, 2010). Using disaggregated data to construct spatial indicators, provides a more detailed geographic picture of urban health and enables inequities to be unmasked (World Health Organization and UN Habitat, 2010).

Using Australian metropolitan and regional cities as a case study, this paper examines the spatial distribution of 'urban liveability' and studies its relationship with neighbourhood disadvantage. It begins with a review of the literature on urban liveability and its relationship to population health, and the study context.

1.1. Tackling the social determinants of health through urban liveability

Globally, the prevalence of non-communicable diseases (NCDs) is increasing, accounting for 71% of all deaths annually (Lozano et al., 2012; WHO, 2022). In Australia, ten NCDs account for 89% of all deaths (Australian Institute of Health, 2020a). Leading NCDs (e.g., cardiovascular disease (CVD), diabetes, and some cancers) share common risk factors including physical inactivity, sedentary behaviours, and obesity.

Several NCDs and their risk factors are affected by city planning decisions including levels of traffic, air and noise pollution, social isolation, personal safety, physical inactivity, prolonged sitting, and unhealthy diets (Munzel et al., 2021). Low density developments with affordable housing on the urban fringe of cities for example, typically have poor access to shops, services, and public transport, which increases motor vehicle dependency, physical inactivity, sedentary behaviours, and obesity (Giles-Corti et al., 2016). Motor vehicle dependence also increases traffic, and exposes residents to air and noise pollution, which in turn increases the risk of CVD and cognitive dysfunction (Munzel et al., 2021; Mueller, Rojas-Rueda, Basagana, et al.; Roswall et al., 2021).

City planning decisions determine access to public transport, employment, green space, shops and services, affordable housing, and walkable neighbourhoods, and the presence of these amenities helps create liveable cities (Giles-Corti et al., 2016). Although 'liveability' is rarely defined (Lowe et al., 2015), globally there is growing discourse articulated by politicians, policymakers, and the public about the desirability of creating 'liveable' cities (World Health Organization, 2021; OECD, 2006; Ministry of Housing and Urban Affairs, 2021). The concept has been popularised through liveability indices developed by the Economist magazine's Intelligence Unit (EIU) and professional services firm, Mercer (Marsal-Llacuna et al., 2015). Both organisations assess cities' potential impacts on quality of life from the perspective of expatriate executives, to inform global companies about hardship allowances (Marsal-Llacuna et al., 2015). Although being ranked a 'liveable city' is often a source of pride and between-city rivalry, these city-wide indices provide no insight into the spatial distribution of amenities within a city (Lowe, Arundel, Hooper, et al.), nor the resources available to enhance the lived-experience of *all* residents (Chernaya, 2019).

Similarly, a limitation of the indicator frameworks adopted to evaluate the UN SDGs and the New Urban Agenda is that they are measured and reported at the national and/or city-wide level. Neither framework specifically recommends that cities develop and map spatial indicators that can be used to identify inequities within cities (World Health Organization and UN Habitat, 2010). Further, many of the SDG indicators assess downstream outcomes (e.g., mode of transport or air quality), rather than indicators of the 'upstream' policies and interventions that will improve those outcomes (e.g., transport policies and infrastructure investments that affect transport mode choice, traffic and air quality). (Giles-Corti et al., 2019).

One means of elevating the importance of city planning for health and health equity, is by conceptualising (Lowe et al., 2015; Badland, Whitzman, Lowe, et al.), measuring, and examining urban liveability from a population health perspective (Badland et al., 2017a; Badland et al., 2015; Badland et al., 2017b; Badland et al., 2017c; Boulange et al., 2017; Davern et al., 2018; Feng et al., 2018; Higgs et al., 2019; Hooper, Boruff, Beesley, Badland, Giles-Corti; Koohsari, Badland, Mavoa, et al.; Madill, Badland, Mavoa, Giles-Corti; Mavoa et al., 2018; Murphy et al., 2018a; Murphy et al., 2016; Murphy et al., 2018b; Murphy et al., 2017; Villanueva et al., 2015). Although the look and feel of urban liveability is context-dependent, the underlying concept from a health determinants' viewpoint, focuses on ensuring all residents have access to basic amenities required for daily living within a walkable catchment (Khorrami et al., 2021; Alderton et al., 2019a; Basu et al., 2021; Ministry of Urban Development, 2017; Kasim et al., 2021). Globally, this idea is reflected in efforts to 'build back better' post-COVID-19, by creating 15- (C40 Cities Climate Leadership Group, 2021) or 20-min (Victorian State Government, 2019; Emery and Thrift, 2021; Royal Town Planning Institute, 2021) cities with active-transport-friendly and amenity-rich neighbourhoods (McNeil, 2011). Indeed, a definition of liveability aligned with this aspiration adopted by the Victorian state government in Australia (Department of Health and Human Services, 2015; Department of Health and Human Services, 2019), is that liveable neighbourhoods are 'safe, socially cohesive and inclusive and environmentally sustainable, with affordable housing linked by public transport, walking and cycling infrastructure to employment, education, health and community services and leisure and cultural opportunities.' (Lowe et al., 2015; Badland, Whitzman, Lowe, et al.)

1.2. Urban liveability indicators

There is growing agreement that quantification of urban liveability is vital to provide a set of standardised key performance indicators for use by city planners to: aid decision-making (Leach et al., 2017); enhance the quality of urban environments for the benefits of citizens (Marsal-Llacuna et al., 2015); enable within and between-city comparisons (Kitchin et al., 2015); evaluate urban policies (Victorian State Government, 2019); and to monitor progress in cities over time (Dora et al., 2015; Marsal-Llacuna et al., 2015).

Urban liveability indicators can be used to benchmark, monitor, and compare differences between cities in access to amenities and infrastructure. Leach (Leach et al., 2017) argues that while indicator choice is often arbitrary, their measurement and assessment method should be fit-for-purpose and enable: (a) decision-making and management; (b) advocacy; (c) participation and consensus building; and (d) research and analysis. However, policy-relevant urban indicators can also be used to evaluate decades of urban planning implementation (Lowe, Arundel, Hooper, et al.; Arundel et al., 2017). For example, urban liveability indicators can assess whether past or current city planning policy and practices are equitably distributed and enable healthy and sustainable development and lifestyles (Watts et al., 2015). Leach et al. (2017), argue that individual indicators should be 'simple, elegant, effective, sensitive to change, measurable and verifiable (preferably in a standardized way), conceptually sound, understandable, unambiguous, objective (value-free) and draw upon data that either exist or are relatively easy to obtain'.

1.3. Context for this study and measuring the liveability of Australian cities

Prior to the COVID-19 pandemic, Australia's population was projected to double by 2050 (Australian Bureau of Statistics, 2013). Three of its state capital metropolitan cities (i.e., referred to hereafter as 'metropolitan' cities) were growing faster than other cities: Perth, Brisbane, and Melbourne. Indeed, by 2050 Melbourne's population was projected to exceed Australia's largest city, Sydney, with both cities projected to become mega-cities in the second half of the 21st century. Despite COVID-19 interrupting population growth, it is anticipated that Australia will continue to attract migrants and grow, albeit at a slower rate than pre-COVID projections (Centre for Population, 2021). Nonetheless, recent trends suggest some redistribution of population, potentially reducing the primacy of Australia's metropolitan cities, with more Australians living and working in regional cities (Bourne et al., 2020; Charles-Edwards et al., 2021). While the full implications of the COVID-19 pandemic are yet to be realised, these trends highlight the importance of continuing to plan for growth in Australia's 21 largest cities, and importantly, to implement city planning policies that promote health and avoid widening inequities.

Rapid population growth places pressure on infrastructure and amenities, so maintaining urban liveability as cities grow is challenging. Despite policy rhetoric about the need for liveable neighbourhoods (Western Australian Planning Commission, 2009) and cities (Department of Infrastructure and Transport, 2011; DELWP, 2017), there is a substantial gap between these aspirations and the timely delivery of amenities and infrastructure on-the-ground in rapidly growing communities (Lowe, Arundel, Hooper, et al.; Curtis and Punter, 2004; Hooper et al., 2014). In the Australian context, this concern was reflected in the establishment of the Australian Government's National Cities Performance Framework of city-wide indicators for Australia's 21 largest cities, that was conceived to inform investments in infrastructure. (Department of Infrastructure Transport Cities and Regional Development).

Using a health-focused definition of liveability, Higgs et al. (2019) developed a spatial composite urban liveability index (ULI) for Melbourne, Victoria. incorporating seven sub-domains of liveability associated with health and wellbeing outcomes: neighbourhood walkability, and access to employment, healthy food, affordable housing, public open space, social infrastructure, and public transport. The ULI was found to be significantly and positively associated with adult walking, cycling, public transport use (Higgs et al., 2019), and physical activity (Higgs et al., 2021), and negatively associated with driving (Higgs et al., 2019) and body mass index (Higgs et al., 2021). Living in established, amenity-rich neighbourhoods with diverse community, cultural, and leisure destinations was also negatively associated with hypertension and Type 2 diabetes (Higgs et al., 2021). These results suggest that living in liveable, walkable neighbourhoods has the potential to reduce health inequities by creating the conditions for good health. Indeed, Turrell et al. (Kamruzzaman et al., 2014) have argued that ubiquitous walkable neighbourhoods in disadvantaged areas have the potential to offset the negative effects of health-compromising behaviours, and reduce neighbourhood inequities in NCDs.

1.4. Spatial and socioeconomic patterning of urban liveability

Despite the potential health benefits of living in liveable neighbourhoods, features that create liveable neighbourhoods appear to be inequitably distributed within Australian cities. Lowe et al. (Lowe, Arundel, Hooper, et al.), found that despite Australian state governments' policies having targets specifying that most urban dwellers should have access to proximate and regular public transport services, only suburbs closer to the central business districts (CBDs) tend to achieved policy targets (Lowe, Arundel, Hooper, et al.). Similarly, Higgs et al. (2019) mapped their composite liveability index for Melbourne, and observed that urban liveability was spatially patterned, with outer suburban areas having lower levels of liveability than those living closer to the CBD. With limited public transport, local amenity, and employment, outer suburban area residents are likely to have higher household transportation expenses, making them vulnerable to mortgage stress in response to fluctuating and rising fuel prices (Dodson and Sipe, 2008).

Inequities in the distribution of amenities, services, and infrastructure within cities, particularly as they grow and gentrify, have prompted scholars to question, 'Liveable for whom?' (Badland, Pearce; Gurstein et al., 2018) They highlight issues about housing affordability (Gurstein et al., 2018), and raise concerns about whether efforts to create more liveable cities have sufficiently focused on reducing health inequities; and question whether vulnerable disadvantaged groups disproportionately 'bear the burden of environmental risk' associated with poor access to local amenities. (Badland, Pearce) Indeed, Badland and Pearce (Badland, Pearce) argue that lower income households face a 'triple jeopardy' of risk; calling for action to reduce health inequities within cities.

Few studies have examined the spatial distribution of urban liveability across cities, nor its association with area-level disadvantage. We hypothesised that those living in more disadvantaged areas would live in the least liveable neighbourhoods. Drawing on urban liveability data for Australia's 21 largest cities, this paper explores the spatial distribution of urban liveability within cities and its relationship with area-level disadvantage, and tests for the consistency of these relationships across metropolitan and regional cities.

2. Method

2.1. Datasets and study areas

2.1.1. Built environment spatial data and area-units of analysis

The analysis involved a dataset of health-related liveability indicators (Lowe, Arundel, Hooper, et al.; Arundel et al., 2017) calculated for address points in Australia's largest 21 cities included in the Australian Government's National Cities Performance Framework. (Department of Infrastructure Transport Cities and Regional Development) These indicators are visualised for use by policymakers, practitioners, and the community through the Australian Urban Observatory https://auo.org.au (Australian Urban Observatory, 2020).

Study areas included all seven Australian state and territory metropolitan cities of Sydney, Melbourne, Brisbane, Perth, Adelaide, Canberra, Hobart, and Darwin (populations ranging from 113,807 in Darwin to 4,691,565 in Sydney), and Australia's 14 largest regional cities: Gold Coast–Tweed Heads, Newcastle–Maitland, Wollongong, Sunshine Coast, Geelong, Townsville, Cairns, Toowoomba, Ballarat, Bendigo, Albury–Wodonga, Mackay, and Launceston (populations ranging from 75,562 in Launceston to 606,249 in Gold Coast–Tweed Heads). Notably, some of the regional cities are conglomerate cities: conurbations adjacent to (e.g., Newcastle-Maitland), or separated by (e.g., Albury-Wodonga: Gold Coast-Tweed Heads) rivers.

2.2. Measures

2.2.1. Outcome measures

The main outcome measure was a composite national Urban Liveability Index (ULI) calculated using nationally consistent data sources across all 21 cities. Data sources and methods used for calculating the indicators included in the ULI are summarised in Table 1. A composite ULI developed for Melbourne by Higgs et al., 2019, 2021, was adapted for the national context in Australia, and is briefly described here. The national ULI comprised 13 indicators derived from built environment measures (see Table 1) including: access to social infrastructure and services (i.e., community, culture, and leisure; education; early years; health and social services; sport and recreation), fresh food, convenience amenities, regularly serviced public transport stops, large public open space, local employment, street intersection connectivity, dwelling density, and housing affordability.

2.2.2. Built environment measures

The ULI and its associated built environment measures, or 'liveability indicators', were calculated for residential address points according to the validated methods described by Higgs et al. (2021), using data sources with national coverage as detailed in Table 1. Residential addresses were identified as proxies for residential locations from the 2018 Geocoded National Address File data. These were restricted to addresses located in Mesh Blocks with dwellings recorded at the 2016 census within each city's urban area (Australian Bureau of Statistics, 2022). Residential address locations were further restricted to those located in Statistical Area 1 (SA1) regions for which the Australian Bureau of

Table 1
Summary of data sources and methods for 13 indicators included in the national ULI composite measure.

Indicator[a]	Specific destinations	Scale	Method
Social infrastructure			Access to specific destinations along the pedestrian road network for each address point was evaluated against destination specific access distance thresholds. A score out of 1 for access for each destination was calculated, such that greater proximity was rewarded. Access indicators were each calculated as average of scores for access within recommended distances of amenities corresponding to that indicator (Higgs et al., 2021).
1 Community, Culture & leisure access	Community centres [b,c]	1000 m	
	Cinema/Theatre [b]	3200 m	
	Libraries [d]	1000 m	
	Museums/Art Galleries [b]	3200 m	
2 Education access	State Primary Schools [e]	1600 m	
	State Secondary Schools [e]	1600 m	
3 Health & social services access	Aged Care [f]	1000 m	
	Community Health Centres [f]	1000 m	
	Dentists [f]	1000 m	
	GP Clinics [f]	1000 m	
	Maternal/Child Health [f]	1000 m	
	Pharmacy	1000 m	
4 Sport & recreation access	Swimming Pools [b]	1200 m	
	Sport/recreation facilities [b]	1200 m	
5 Early years access	Childcare meeting quality requirements [g]		
	any	800 m	
	out of school hours	1600 m	
Food			
6 Fresh food access	Fruit/vegetable grocer [b]	1000 m	
	Meat/seafood [b]	3200 m	
	Supermarkets [b] [i]	1000 m	
Convenience amenities			
7 Convenience access[i]	Convenience store [b]	1000 m	
	Newsagent [b]	3200 m	
	Petrol station [b]	1000 m	
Transport			Average daytime (7am to 7pm) weekday service frequency was determined across all public transport modes (e.g., bus, ferry, train, tram, as applicable) for stops during the Spring school term period of 8 October and December 5, 2019.
8 % Dwellings with access to regular public transport	Public transport stops with average daytime weekday service frequency 30 min[h]	400 m	
Public Open Space			Access to large public open space was evaluated as per access to destinations, except using pseudo-access points generated at 20 m intervals along the boundaries of areas of open space located within 30 m of the walkable road network and having publicly accessible area larger than 1.5 ha.
9 % Dwellings with access to large public open space (>1.5 ha)	Public open space entry point proxy locations [b]	400 m	
Walkability components[i]			
10 Street connectivity per km[c]	Pedestrian network and intersections [b]	1600 m	Street connectivity was calculated as the number of pedestrian network intersections intersecting the local walkable network buffer, divided by its area in square kilometres.
11 Dwelling density per hectare	Pedestrian network [b] and Mesh Block areas with dwelling counts[80,81]	1600 m	Dwelling density was calculated as the sum of dwellings within Mesh Blocks (small statistical geography areas, equivalent to a street block) intersecting the local walkable network buffer, divided by its area in hectares.
Housing			Housing affordability stress is the proportion of low-income households (in the bottom 40% of the Australian income distribution) spending more than 30% of their income on housing costs. For inclusion in the ULI, this measure was reverse scaled to represent 'housing affordability'.
12 Housing affordability	Housing expenditure by relative household income[82]	Statistical Area 1	
Employment			The percentage of employed persons working in the same Statistical Area 3 (broader catchment, SA3) as the local area (Statistical Area 1; SA1) in which they live.
13 Local employment	Place of work (SA3) by place of residence (SA1)[82]	Statistical Area 1	

[a] All indicators were calculated for sample points derived from the Geoscape Open Geocoded-National Address File (G-NAF; data.gov.au, 2018).
[b] OpenStreetMap contributors. 2018. Planet dump retrieved from https://planet.osm.org/planet/2018/planet-180903.osm.bz2.
[c] Healthy Liveable Cities Lab. 2016. National community centres database (in-house geocoding).
[d] Healthy Liveable Cities Lab. 2018. National state library database (collated from open data and in-house geocoding; 2015–18).
[e] Australian Curriculum, Assessment and Reporting Authority (ACARA). 2018. Australian Schools List (in-house geocoding; 2015–18).
[f] AURIN. 2018. Healthdirect Australia National Health Services Directory. https://aurin.org.au/national-health-services-directory/.
[g] Australian Children's Education & Care Quality Authority (ACECQA) 2019; retrieved, cleaned and geocoded in 2019.
[h] OpenMobilityData. 2019. Australian state transport agency GTFS feeds. https://openmobilitydata.org/.
[i] NB: Walkability index was calculated as sum of standardised scores for dwelling- and street intersection-densities and access to daily living amenities, including convenience amenities (i.e., convenience store, newsagent, or petrol station); supermarket; and public transport stop (i.e., bus, ferry, tram, or train stop) within 1600 m.

Statistics (ABS) Index of Relative Socioeconomic Disadvantage (IRSD) had been calculated, being areas with a minimum usual resident population (greater than 10 persons) (Australian Bureau of Statistics, 2016). Mesh Blocks are the smallest geographic areas in the Australian Statistical Geography Standard (ASGS), while SA1s are the second smallest geographical areas, with a population of 200–800 people and an average population size of 445 people in metropolitan cities and 432 people in regional cities. SA1 areas are designed for dissemination of census data, including measures of neighbourhood disadvantage like the IRSD.

Liveability indicator averages were calculated for each Mesh Block with dwellings, and for SA1s using Mesh Block dwelling counts as weights. Calculating dwelling-weighted indicator averages for each SA1 meant that our estimates reflected the average experience with regard to urban liveability of 'neighbourhoods' for the households according to their geographic distribution and internal clustering, as determined using Mesh Block dwelling counts (Higgs et al., 2021).

To enable between-city comparisons, prior to aggregation at SA1 level, we developed a national ULI calculated relative to address points across all cities, with a national average benchmark score of 100. The 21-city national liveability dataset contained built environment measures for 39,967 SA1 neighbourhoods in total.

Walkable neighbourhoods with increased density, mixed land-use, and street connectivity are the building blocks of a liveable city. (Hooper, Knuiman, Foster, Giles-Corti) Hence, to further assist in comparing cities, two additional composite built environment measures (Hooper, Knuiman, Foster, Giles-Corti) were developed: a walkability index within 1600 m of residences calculated as a sum of standardised scores for dwelling- and street intersection-densities plus access to daily living amenities (i.e.,/3: sum of access to a supermarket, convenience amenities, and/or any public transport stop)) (Mavoa et al., 2018); and a social infrastructure mix score (/16: sum of access scores of the 16 specific social infrastructure destinations within threshold distances listed in Table 1). (Davern et al., 2018).

2.2.3. Neighbourhood disadvantage

The ABS IRSD was used to measure area-level socioeconomic characteristics (Australian Bureau of Statistics, 2016). The IRSD score uses 17 variables to reflect area-level disadvantage including education, occupation, income, unemployment, household structure, and household tenure, among others (Australian Bureau of Statistics, 2016). IRSD scores for SA1s from 2016 were obtained from the ABS website and linked to the built environment data using their unique SA1 identifier. The derived IRSD scores were then grouped into quintiles for each city, with Q5 denoting the 20% least disadvantaged areas in each city and Q1 denoting the 20% most disadvantaged areas.

2.3. Data analysis

Data analyses were undertaken using the statistical software Stata 15.1 (StataCorp, 2022). First, using descriptive statistics, general patterns were investigated for the national ULI and its domains by metropolitan and regional cities. Second, we examined the spatial distribution of the ULI within metropolitan and regional cities. Third, Ordinary Least Squares linear regression (OLS) models were used to estimate the association between the IRSD quintiles and the ULI for each city.

The output from these models was presented as regression coefficients and their 95% confidence intervals. We also specified interaction models between IRSD and liveability in the metropolitan and regional cities to test whether the association between neighbourhood disadvantage and liveability was the same or different across cities. Outputs from the interaction models are presented graphically in Figures A1 and A2 in Appendix A. The interactions were found to be statistically significant ($p < 0.001$), confirming associations between disadvantage and liveability differed by city and supported our decision to undertake city-specific analyses. Additional mapping was undertaken using QGIS 3.16 (QGIS Development Team, 2022).

3. Results

3.1. Descriptive statistics of the national ULI and its sub-indicator built-environment measures

3.1.1. Overall results

In metropolitan cities, the average national ULI score was 100.4 (range 82.6–119.2); and the average IRSD score was 1017.4 (range 325–1186) (see Table 2). In regional cities the average ULI score was 98.1 (range 84.6–115.8); and the average IRSD score was 989.3 (331–1159) (see Table 3).

Some of the largest differences observed between metropolitan and regional cities in underlying built environment measures included in the ULI, related to public transport access (on average 48.0% and 25.3% of dwellings had proximate and frequent public transport access respectively); and access to local employment (on average 30.4% and 60.2% respectively). On average, compared with metropolitan cities, regional cities had poorer access to public transport, but better access to local employment.

3.1.2. Metropolitan cities

Among the metropolitan cities, the average ULI score for Sydney (101.5), Melbourne (101.2) and Adelaide (100.1) were above the national average, while for all other metropolitan cities scores were slightly below average. However, average city-wide scores mask the variability between and within cities as shown in Fig. 1.

When compared with the other 21 cities nationally, the liveability of over 50% of neighbourhoods in Australia's two large cities - Sydney and Melbourne - were above average (see Fig. 1(a)). However, there was considerable variation with outlier neighbourhoods at both low and high extremes, but particularly at the higher levels of liveability. Conversely, in Adelaide, although liveability scores for 50% of neighbourhoods were above average, outlier neighbourhoods tended to have low liveability scores. In Brisbane, median neighbourhood liveability was below average; but in Perth, Darwin, and Hobart almost 75% of neighbourhoods scored below average. However, in Perth, Brisbane and Australia's national capital city Canberra, there was evidence of more highly liveable outlier neighbourhoods, also indicative of disparities in those cities.

In terms of the built environment measures included in the ULI, Sydney had the highest mean values for seven of the 15 sub-indicators, although most notably, for dwelling density, access to social infrastructure, and walkability. However, many of these sub-indicators in Sydney also had the greatest variation, suggestive of considerable within-city inequities. Canberra had the highest average neighbourhood values for street connectivity, and access to public transport and public open space.

On average, a greater percentage of employed persons were able to access local employment opportunities in Australia's smallest metropolitan cities (Hobart and Darwin; at least 40%) than in Sydney and Perth (approximately 30%).

3.1.3. Regional cities

Compared with other regional cities, Geelong in the state of Victoria scored highest for liveability overall, and its mean ULI score (100.6) and that for the Victorian regional city of Ballarat (100.3) were just above the national average for all 21 cities. For all other regional cities, the mean ULI scores were just below average.

However, within-city variations in the liveability scores in regional cities are evident in the boxplots of medians in Fig. 1(b). As shown, 50% or more of neighbourhoods in Geelong and Ballarat scored above the national average in liveability compared with the 21 cities in the study. However, 50% or more of neighbourhoods in other regional cities scored below the national average of liveability. Indeed, 75% or more of neighbourhoods in the Sunshine Coast and Cairns scored below the national average.

In terms of the underlying built environment measures included in the ULI, compared with other regional cities, neighbourhoods in Geelong had the highest levels of access to social infrastructure overall (6.0/16), with above average access to health, social, and early years services, as well as having the second highest score for walkability. Neighbourhoods in Ballarat had the highest mean access to proximate and regular public transport (43.4%), almost twice as high as the overall regional city estimate of 25.3%. Ballarat neighbourhoods also had the highest levels of access to education, sport and recreation, and public open space compared with other regional cities. On average, neighbourhoods in Queensland's Gold Coast-Tweed Heads were slightly more walkable and denser compared with neighbourhoods in other regional cities. We estimated that on average, more than 50% of employed persons could access employment opportunities local to their neighbourhood in 10 of the 13 regional cities, suggesting there is potential to increase active

Table 2
Liveability summary statistics, Mean (SD), of Australian metropolitan cities ordered by population (from largest to smallest).

Cities sorted by population	Sydney	Melbourne	Brisbane	Perth	Adelaide	Canberra	Hobart	Darwin	Total
SA1s in each metropolitan city (n)	10,408	9668	4857	4153	2881	1012	489	254	33,722
Liveability domain									
National urban liveability index (ULI)	101.5 (5.4)	101.2 (5.2)	98.6 (4.9)	98.1 (4.1)	100.1 (3.9)	99.8 (3.8)	97.2 (5.5)	97.9 (4.1)	100.4 (5.2)
Community, Culture & leisure (/100)	30.4 (23.6)	25.9 (23.2)	20.6 (20.9)	20.2 (19.3)	26.6 (21.5)	19.1 (17.3)	27.2 (23.8)	28.3 (15.9)	25.7 (22.6)
Education (/100)	60.6 (23.9)	58.7 (24.7)	45.7 (25.9)	51.1 (22.7)	51.4 (22.2)	58.6 (23.4)	44.3 (28.2)	50.7 (28.1)	55.6 (24.9)
Health & social services (/100)	41.8 (25.9)	42.6 (25.7)	34.3 (23.9)	33.9 (23.5)	38.9 (22.3)	24.6 (21.0)	24.2 (23.4)	22.4 (20.7)	38.8 (25.2)
Sport & recreation (/100)	41.9 (16.9)	41.3 (16.6)	35.8 (17.8)	32.7 (17.4)	42.2 (14.6)	40.5 (17.2)	28.3 (19.4)	34.9 (15.9)	39.4 (17.2)
Early years (/100)	64.8 (28.8)	66.3 (26.2)	55.3 (30.3)	46.0 (29.4)	58.7 (26.4)	54.2 (26.2)	41.5 (32.8)	45.8 (29.8)	60.2 (29.1)
Food environment (/100)	33.2 (26.7)	33.2 (24.9)	25.7 (22.1)	19.9 (19.3)	30.6 (22.1)	31.6 (20.3)	24.7 (20.1)	13.3 (14.9)	29.9 (24.5)
Convenience store (/100)	38.8 (29.2)	45.3 (29.5)	30.1 (26.3)	20.7 (21.5)	30.5 (24.0)	34.9 (24.2)	26.1 (26.8)	34.5 (21.1)	36.1 (28.5)
Public transport (%)	57.5 (34.2)	45.7 (35.6)	32.9 (33.7)	44.2 (32.9)	54.3 (30.2)	60.4 (28.3)	23.9 (30.7)	23.2 (28.0)	48.0 (35.0)
Public open space (%)	49.8 (34.1)	48.2 (32.5)	54.4 (32.9)	55.8 (31.5)	46.8 (34.5)	68.0 (29.8)	40.6 (30.7)	46.8 (33.1)	50.9 (33.3)
Dwelling density (ha)	20.0 (11.7)	15.2 (8.4)	12.6 (5.5)	12.0 (3.7)	12.0 (2.9)	9.2 (2.4)	10.2 (3.0)	10.4 (3.3)	15.4 (9.0)
Street connectivity (/km (United Nations, 2016))	78.4 (29.8)	88.0 (29.5)	80.1 (21.1)	78.6 (22.2)	86.1 (18.3)	101.7 (21.1)	59.5 (15.7)	76.1 (13.7)	82.5 (27.1)
Housing stress (%)	37.4 (19.6)	35.9 (16.8)	38.6 (18.8)	36.9 (17.5)	32.9 (13.0)	33.1 (21.4)	31.0 (11.9)	41.1 (21.8)	36.5 (18.0)
Local employment (%)	31.7 (14.9)	29.3 (12.1)	28.4 (12.7)	31.9 (12.6)	27.3 (10.9)	29.6 (12.8)	44.9 (20.3)	42.9 (14.7)	30.4 (13.6)
Social infrastructure (/16)	7.1 (3.1)	6.9 (3.0)	5.6 (3.0)	5.4 (2.5)	6.5 (2.6)	5.3 (2.4)	4.8 (3.2)	5.1 (2.4)	6.45 (3.0)
Walkability	1.2 (3.3)	0.9 (2.7)	−0.1 (2.3)	−0.4 (1.7)	0.3 (1.5)	0.4 (1.4)	−1.5 (1.9)	−0.5 (1.5)	0.6 (2.7)
Neighbourhood disadvantage	1017.3 (104.3)	1021.0 (88.0)	1014.5 (94.9)	1024.6 (75.3)	987.9 (100.2)	1073.5 (56.1)	1073.5 (56.1)	1035.2 (85.6)	1017.4 (94.9)

commuting in these cities. See Appendices B1 and B2 for further detailed descriptive statistics of variables for metropolitan and regional cities.

3.2. Spatial distribution of urban liveability within cities

To further explore variations in access to urban liveability, Figs. 2 and 3 map the spatial distribution of liveability across cities, with the main CBD approximated by the location of the General Postal Office. Larger scale maps for each city are available in the supplementary materials. Compared with outer suburban neighbourhoods, inner-city and middle-suburban neighbourhoods of most Australian metropolitan (Fig. 2) and regional (Fig. 3) cities tend to be more liveable, with more walkable neighbourhoods and better access to amenities required for daily living. However, this pattern was not evident at all in the Sunshine Coast or Maitland (part of the Newcastle-Maitland conurbation).

3.3. Urban liveability and socioeconomic disadvantage within cities

The final set of analyses examined associations between neighbourhood disadvantage and urban liveability. In Australia's larger cities – Sydney, Melbourne, Perth, and to a lesser extent Brisbane (ranging in population size from 1.9 to 4.7 m) - the ULI scores were significantly lower in the most disadvantaged areas (Q1 & Q2) compared with the least disadvantaged (Q5) (see Table 4). However, this pattern was reversed in all smaller metropolitan cities, except Hobart where there was no significant association. In Adelaide, Canberra, and Darwin (smaller metropolitan cities, ranging in population from 113,807 to 1.2 million), the more disadvantaged areas appeared to have significantly higher ULI scores than the least disadvantaged areas.

In 11 of the 13 regional cities, the pattern of associations between neighbourhood disadvantage and liveability were like those observed for Australia's smaller metropolitan cities. Namely, the more socioeconomically disadvantaged areas tended to have significantly higher levels of liveability than the least disadvantaged areas. As noted in the Methods, the interaction models confirming the statistically significant associations between disadvantage and liveability across the metropolitan and regional cities are presented graphically in Figures A1 and A2 in Appendix A.

3.4. Spatial distribution of area-level disadvantage within metropolitan and regional cities

To better understand the patterns observed in Table 4, the spatial distribution of area-level disadvantage was mapped (see Figs. 3 and 4), with CBDs approximated by the location of each city's General Postal Office. Larger scale maps for each city are available in the supplementary materials.

As can be seen in Sydney, Melbourne, and Perth (Fig. 4), the most disadvantaged areas appeared to be concentrated in the outer suburban/ middle level areas of those cities, with the least disadvantaged areas located closer to the inner city and along the coast or river. Nonetheless, these patterns were not entirely consistent. For example, in Perth, industrial areas are in the coastal suburbs to the south of the city, and these areas tended to be more disadvantaged. The map for Adelaide in Fig. 4 also shows that in addition to the urban fringe north and south of the city, some of the most disadvantaged areas appeared to be located near the inner-city, reflecting the pattern also observed in Table 4.

In all but three regional cities - i.e., Gold Coast-Tweed Heads, Townsville, and Sunshine Coast - the most disadvantaged areas appeared to be located near the city centre (Fig. 5). Conversely, in many of the regional cities, the least disadvantaged suburbs tended to be in outer suburban areas. In coastal regional cities (e.g., Wollongong, Geelong, Sunshine Coast, Newcastle-Maitland), many of the least disadvantaged suburbs were also located on the coast.

4. Discussion

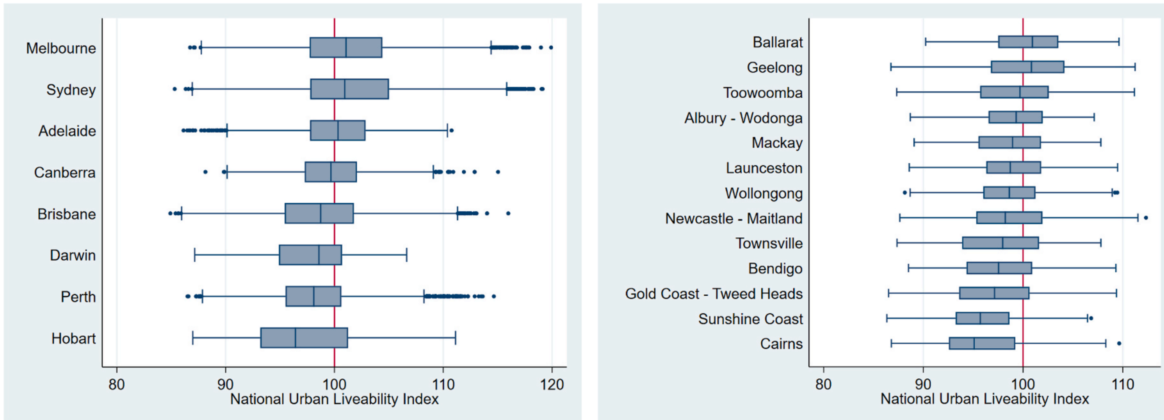
Our findings demonstrate how city-wide summary measures mask inequities in access to amenities and infrastructure that support the health and wellbeing of urban residents. Urban liveability was found to be spatially patterned in Australian cities. Outer suburban areas consistently had lower liveability scores. However, depending upon the size of the city, we found that lower liveability did not always amplify socioeconomic inequities, because in smaller cities it was often higher socioeconomic areas often located in outer-suburban areas. A discussion of within- and between-city differences follows, along with the policy implications of our findings.

4.1. Within and between-city differences in urban liveability

Overall, we found relatively modest differences between cities in their average city-wide urban liveability scores. As might be expected, Australia's largest metropolitan cities – Sydney and Melbourne - scored higher and above average compared with other metropolitan and regional cities. Yet the liveability scores of two regional cities – Geelong and Ballarat – were also slightly higher than many larger metropolitan

Table 3
Liveability characteristics, Mean (SD), of Australian regional cities ordered by population size (from largest to smallest).

Cities sorted by population	Gold Coast - Tweed Heads	Newcastle - Maitland	Wollongong	Sunshine Coast	Geelong	Townsville	Cairns	Toowoomba	Ballarat	Bendigo	Albury - Wodonga	Mackay	Launceston	Regional Cities
SA1s in each regional city (n)	1327	1058	677	601	523	424	335	302	209	208	199	182	200	6245
Liveability domain														
National urban liveability index (ULI)	97.1 (4.6)	98.9 (5.02)	99.1 (3.9)	95.9 (3.7)	100.6 (4.9)	97.5 (4.9)	96.1 (4.5)	98.8 (5.2)	100.3 (4.3)	97.7 (4.4)	99.1 (3.8)	98.6 (4.3)	98.9 (4.6)	98.1 (4.8)
Community, Culture & leisure (/100)	17.5 (16.5)	21.7 (20.5)	26.7 (19.8)	10.3 (15.1)	23.5 (16.9)	19.6 (18.5)	10.6 (16.3)	22.3 (19.9)	35.4 (21.5)	23.9 (20.6)	29.6 (21.5)	15.8 (13.9)	19.6 (19.9)	30.4 (23.6)
Education (/100)	30.6 (25.7)	52.4 (22.7)	55.5 (24.5)	29.4 (27.4)	55.3 (28.7)	39.0 (27.9)	34.8 (28.6)	43.2 (24.4)	58.1 (26.7)	45.3 (25.4)	51.0 (29.6)	43.2 (24.9)	49.1 (25.6)	55.6 (24.9)
Health & social services (/100)	28.4 (24.3)	27.4 (23.2)	30.6 (24.2)	28.7 (22.7)	35.1 (24.3)	26.3 (22.9)	25.9 (24.8)	33.1 (24.9)	27.3 (24.0)	29.6 (24.5)	28.4 (22.6)	24.5 (21.9)	23.4 (20.1)	38.8 (25.2)
Sport & recreation (/100)	28.9 (20.2)	36.6 (17.5)	37.5 (19.3)	25.4 (18.8)	38.7 (15.1)	28.4 (21.4)	23.7 (18.8)	35.9 (22.1)	42.0 (12.9)	36.7 (19.5)	42.3 (13.8)	29.7 (26.8)	38.6 (13.2)	39.4 (17.2)
Early years (/100)	43.1 (30.4)	50.9 (30.4)	50.1 (29.7)	35.7 (28.9)	55.7 (29.9)	50.3 (31.6)	42.1 (32.5)	51.7 (31.6)	27.8 (24.2)	41.3 (28.8)	53.5 (28.7)	42.8 (32.3)	36.6 (33.0)	60.2 (29.1)
Food environment (/100)	19.9 (18.4)	23.4 (24.5)	12.6 (17.3)	8.7 (13.2)	26.1 (21.7)	16.4 (16.5)	13.7 (17.9)	20.9 (19.1)	34.4 (23.0)	7.7 (9.8)	9.7 (11.6)	31.8 (21.8)	36.3 (23.3)	29.9 (24.5)
Convenience store (/100)	21.1 (21.9)	22.6 (25.9)	14.8 (18.6)	9.9 (13.9)	35.8 (27.6)	23.2 (21.5)	10.7 (13.5)	29.9 (27.1)	36.3 (29.7)	18.6 (20.7)	18.4 (17.2)	45.4 (27.0)	34.9 (25.4)	36.1 (28.5)
Public transport (%)	24.0 (32.5)	31.3 (33.2)	32.7 (33.2)	23.6 (30.6)	39.0 (34.8)	22.3 (28.4)	15.0 (25.8)	4.2 (15.0)	43.4 (30.7)	36.6 (32.0)	4.8 (13.8)	0.7 (5.2)	13.3 (24.9)	25.3 (31.9)
Public open space (%)	53.9 (34.4)	57.2 (32.5)	42.6 (33.0)	51.2 (33.8)	44.6 (30.8)	43.4 (35.0)	42.6 (30.4)	42.1 (32.1)	56.0 (30.1)	42.7 (29.0)	51.7 (30.7)	54.3 (29.2)	38.7 (29.4)	49.5 (33.2)
Dwelling density (ha)	14.8 (8.1)	11.4 (3.3)	12.6 (3.7)	11.6 (3.8)	11.1 (2.6)	10.3 (2.3)	11.6 (3.0)	9.8 (2.8)	8.9 (2.2)	7.7 (1.8)	8.7 (2.1)	9.9 (2.2)	9.9 (2.2)	11.7 (4.0)
Street connectivity (/km (United Nations, 2016))	73.2 (19.0)	68.3 (17.8)	71.3 (14.7)	71.3 (19.7)	75.0 (16.7)	62.6 (13.9)	65.1 (13.6)	63.6 (18.8)	71.4 (15.9)	66.6 (15.5)	78.1 (13.2)	60.9 (8.0)	61.1 (16.4)	69.6 (17.5)
Housing stress (%)	40.9 (19.7)	32.4 (13.8)	30.3 (14.6)	35.4 (15.8)	31.1 (11.1)	43.1 (16.1)	40.8 (14.2)	33.5 (15.4)	32.0 (11.3)	31.4 (10.9)	32.7 (11.5)	35.2 (13.2)	30.6 (10.9)	35.4 (15.9)
Local employment (%)	37.3 (12.7)	51.6 (16.2)	48.4 (11.5)	49.4 (13.5)	70.8 (16.8)	93.9 (3.3)	68.1 (23.5)	89.1 (5.1)	87.3 (4.4)	85.5 (5.2)	69.7 (6.3)	87.9 (5.1)	83.9 (13.2)	60.2 (23.3)
Social infrastructure (/16)	4.5 (2.7)	5.3 (2.8)	5.8 (2.8)	3.9 (2.6)	6.0 (2.9)	4.7 (3.2)	4.0 (3.1)	5.5 (3.1)	5.6 (2.7)	5.2 (3.2)	5.8 (2.9)	4.4 (2.8)	4.7 (2.8)	5.0 (2.9)
Walkability	−0.37 (2.5)	−1.07 (1.8)	−0.8 (1.5)	−1.02 (2.0)	−0.4 (1.6)	−1.6 (1.7)	−1.3 (1.7)	−1.4 (2.3)	−1.1 (1.6)	−1.9 (1.6)	−0.91 (1.6)	−1.2 (1.2)	−1.0 (1.6)	−0.9 (2.0)
Neighbourhood disadvantage	1012.5 (67.8)	978.4 (99.8)	986.9 (100.4)	1012.9 (63.0)	991.1 (100.0)	985.1 (86.8)	975.4 (108.4)	988.9 (81.6)	966.5 (102.2)	967.2 (93.7)	961.5 (115.1)	976.7 (76.2)	945.2 (113.0)	989.3 (91.9)



a) **Metropolitan cities** b) **Regional cities**

Fig. 1. Distribution of neighbourhood average national liveability index scores for 21 cities.

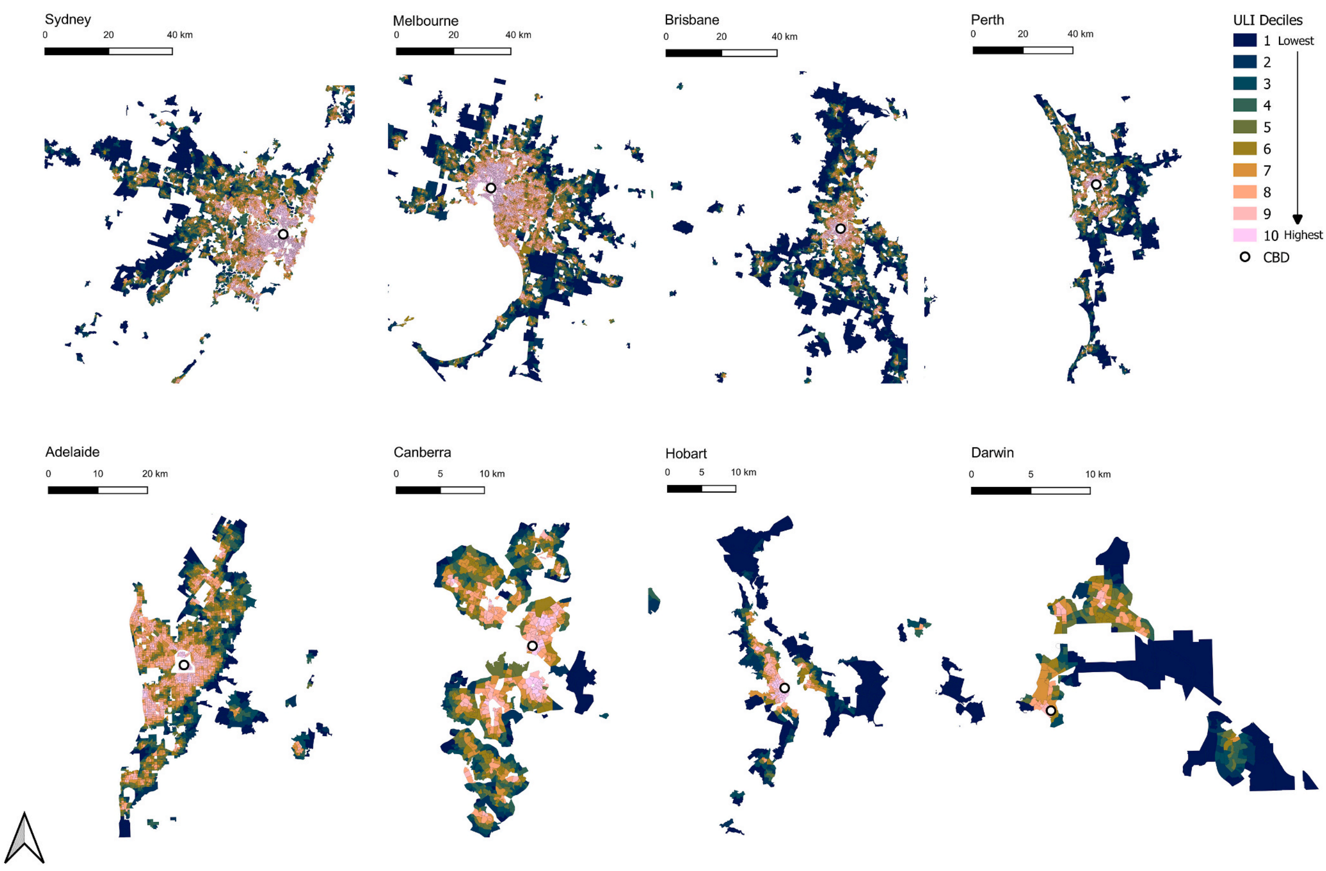


Fig. 2. Spatial distribution of national urban liveability within Australian metropolitan cities.

cities. These results suggest that with appropriate planning and investment in social infrastructure (Klinenberg, 2018), regional cities have the potential to be just as liveable and health-promoting as larger metropolitan cities.

However, despite modest variations in average urban liveability scores between Australia's largest 21 cities, in both metropolitan and regional cities there were important spatial disparities in access to the basic amenities required for daily living. Indeed, in many smaller metropolitan cities and most regional cities, more than 50% of neighbourhoods scored below the national average for liveability, and in some of these cities, 75% of neighbourhoods did so.

These results are important because as noted previously, Higgs et al. found that higher urban liveability is associated with increased active transportation (Higgs et al., 2019), and offers significant cardiometabolic benefits (Higgs et al., 2021). In low-liveable areas residents were also more likely to drive (Higgs et al., 2019). This increases mortgage-stress vulnerability – particularly in low-income areas - when oil prices fluctuate (Dodson and Sipe, 2008), as is the case in 2022, due to the war in Ukraine. Moreover, as argued by McShane and Coffey access to local amenities and social infrastructure helps build social connectedness, community capacity and resilience in the event of other major events such as COVID-19 or natural disasters (McShane and

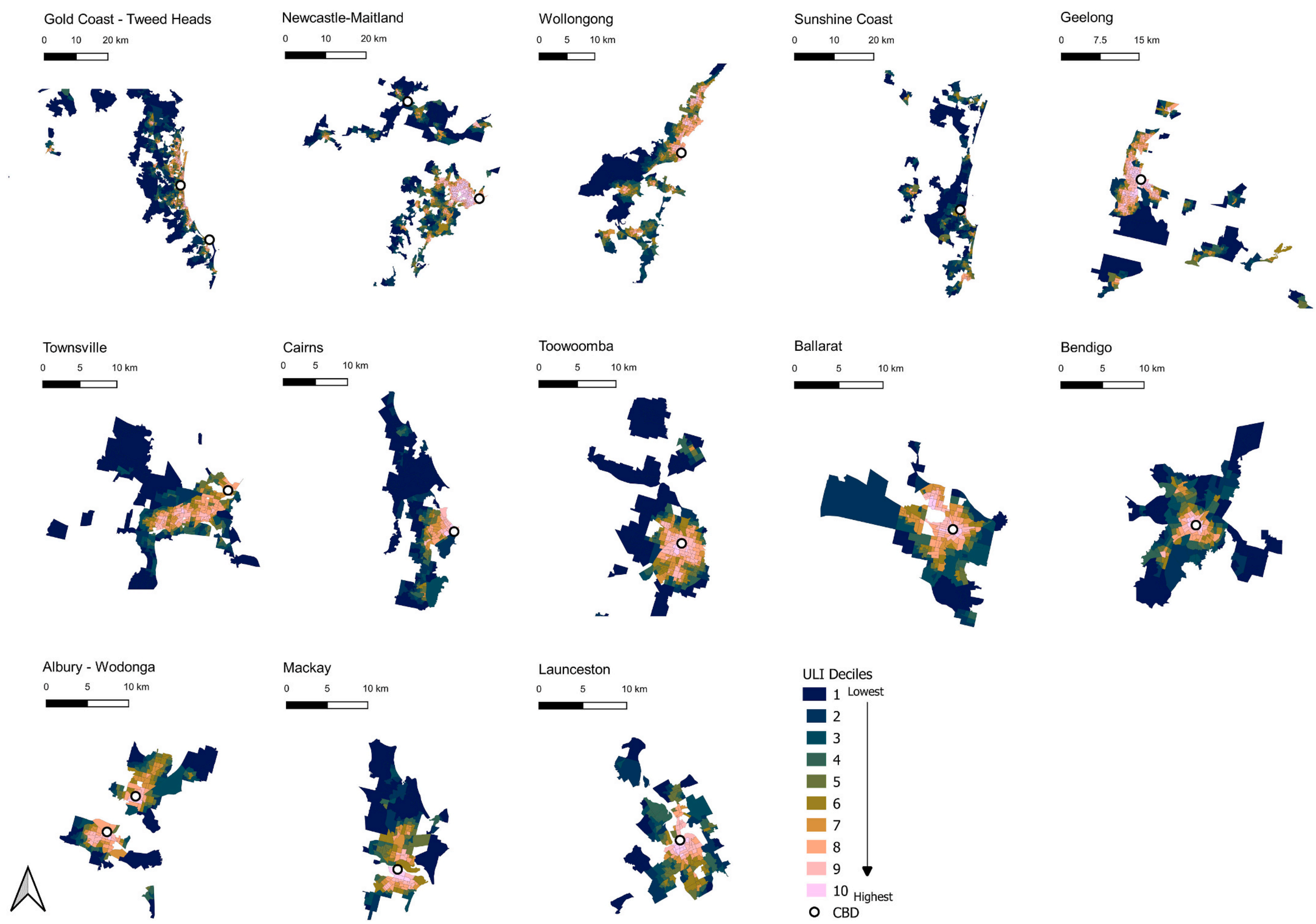


Fig. 3. Spatial distribution of national urban liveability within Australian regional cities.

Coffey, 2022).

Hence, the spatial patterning of urban liveability is of concern. Consistent with previous studies, in Melbourne (Higgs et al., 2019), Australia (Lowe, Arundel, Hooper, et al.; Dodson and Sipe, 2008; Wiesel et al., 2017; Pawson, Herath), and elsewhere (Boeing et al., 2022; Bartzokas-Tsiompras et al., 2020), we confirmed that compared with inner or middle-level suburbs, outer suburban areas are the least liveable with poorer access to walkable neighbourhoods, local amenities and public transport. Yet contrary to our hypothesis that liveability would be negatively associated with area-level disadvantage, we found that this relationship varied across cities. As anticipated, in Australia's four largest cities (Sydney, Melbourne, Brisbane, and Perth), urban liveability was significantly lower in more disadvantaged areas compared with least disadvantaged areas. However, in most of Australia's smaller cities, this pattern was reversed. We found that some of the most disadvantaged areas were more liveable than some of the least disadvantage areas.

These results reflect differences between cities in the location of low-income households, highlighting the value of context-specific evidence to inform policies designed to reduce inequities. Our maps showed that in the smaller metropolitan and regional cities, some of the *most* disadvantaged areas were in inner-city neighbourhoods, where there is greater access to health-supportive amenities and infrastructure. Conversely, in these cities, higher socio-economic areas were in outer suburban areas, with poor access to amenity. In smaller, less congested cities, commuting by private motor vehicle is more convenient than in larger cities, making it attractive for wealthier residents to live in larger outer suburban properties. While socioeconomic disadvantage is of less concern in these contexts, outer suburban areas remain highly motor vehicle dependent, discourage active forms of transport (Higgs et al., 2019) and foster unsustainable lifestyles (Watts et al., 2015). Low density outer-suburban sprawl also hinders these smaller cities from achieving sustainable development (FitzRoy and Smith, 1998) or creating 'complete' communities with net-zero emissions (C40 Cities Climate Leadership Group, 2021), while increasing traffic congestion as regional cities grow (FitzRoy and Smith, 1998).

4.2. City size matters

From an equity perspective, our results suggest that city size matters, reinforcing Sarkar et al.'s (Sarkar et al., 2022) argument that 'big cities are the engines of inequality'. Our results confirm that disadvantage has been suburbanised in larger Australian cities, corroborating earlier findings from Sydney (Randolph and Tice, 2014). While larger cities offer opportunities, they have the potential to widen inequities by displacing lower income households from amenity-rich areas to poorly-served low density outer suburban areas as they grow and gentrify (Badland, Pearce; Gurstein et al., 2018).

This was not yet the case in smaller metropolitan and regional cities, presenting an opportunity for these cities to avoid repeating the mistakes made in larger cities. Our findings raise questions about how urban policy can be used to support smaller cities as they grow, to prevent lower income households being displaced from amenity-rich neighbourhoods.

This concern has been amplified in the shadow of the COVID-19 pandemic. With restricted movements and lockdowns, many

Table 4
Linear regression results for liveability index scores and IRSD quintiles within cities in Australian metropolitan and regional cities, ranked by population size.

	Population	IRSD quintiles relative to Q5 (least disadvantage) in each city: Coef. (95% CI)			
		Q4	Q3	Q2	Q1 (most disadvantage)
Metropolitan cities					
Sydney	4,691,565	**0.49** (0.17, 0.81)	−0.17 (−0.49, 0.16)	**−0.57** (−0.89, −0.25)	**−0.93** (−1.25, −0.61)
Melbourne	4,367,152	**−0.48** (−0.81, −0.16)	**−1.26** (−1.59, −0.94)	**−1.89** (−2.22, −1.57)	**−1.01** (−1.33, −0.68)
Brisbane	2,148,535	0.25 (−0.22, 0.72)	−0.03 (−0.50, 0.44)	−0.19 (−0.65, 0.28)	**−0.51** (−0.98, −0.04)
Perth	1,885,053	**−0.69** (−1.13, −0.24)	**−1.43** (−1.87, −0.98)	**−1.72** (−2.16, −1.27)	**−2.43** (−2.88, −1.99)
Adelaide	1,244,460	**1.30** (0.77, 1.82)	**1.27** (0.74, 1.80)	**1.52** (0.99, 2.05)	**1.32** (0.80, 1.85)
Canberra	387,616	**0.98** (0.10, 1.87)	**1.66** (0.77, 2.54)	**1.97** (1.09, 2.86)	**2.32** (1.43, 3.21)
Hobart	197,708	**1.80** (0.22, 3.39)	0.68 (−0.92, 2.28)	0.45 (−1.13, 2.04)	−0.51 (−2.1, 1.08)
Darwin	113,807	**2.65** (0.82, 4.48)	**4.09** (2.23, 5.95)	**3.77** (1.93, 5.61)	**3.56** (1.72, 5.40)
Regional cities					
Gold Coast - Tweed Heads	606,249	**2.45** (1.65, 3.25)	**3.46** (2.67, 4.26)	**4.41** (3.61, 5.20)	**5.93** (5.13, 6.72)
Newcastle - Maitland	449,014	0.13 (−0.91, 1.17)	**2.25** (1.22, 3.28)	**1.51** (0.48, 2.53)	0.39 (−0.64, 1.43)
Wollongong	282,322	**2.61** (1.58, 3.64)	**3.84** (2.81, 4.88)	**4.25** (3.22, 5.29)	**3.33** (2.29, 4.36)
Sunshine Coast	272,865	**2.07** (1.06, 3.09)	**3.07** (2.06, 4.08)	**4.38** (3.37, 5.39)	**5.98** (4.97, 6.99)
Geelong	232,288	**3.55** (2.16, 4.95)	**3.76** (2.36, 5.15)	**3.81** (2.42, 5.20)	**4.35** (2.96, 5.74)
Townsville	167,949	0.48 (−1.13, 2.09)	**3.30** (1.69, 4.90)	**4.12** (2.51, 5.73)	**3.95** (2.35, 5.56)
Cairns	144,665	**2.08** (0.48, 3.68)	**3.05** (1.45, 4.65)	**6.09** (4.48, 7.70)	**8.94** (7.35, 10.53)
Toowoomba	120,844	**2.74** (0.99, 4.49)	**5.97** (4.20, 7.74)	**7.24** (5.48, 9.01)	**7.94** (6.18, 9.69)
Ballarat	93,431	**2.72** (0.72, 4.72)	**4.19** (2.17, 6.22)	**5.15** (3.17, 7.12)	**5.02** (3.01, 7.03)
Bendigo	92,365	**2.53** (0.38, 4.68)	**4.97** (2.83, 7.10)	**3.94** (1.79, 6.09)	**5.73** (3.60, 7.87)
Albury - Wodonga	84,845	**3.31** (1.65, 4.97)	**4.91** (3.22, 6.60)	**7.68** (6.01, 9.35)	**7.17** (5.50, 8.84)
Mackay	80,143	**2.89** (0.91, 4.88)	**3.79** (1.78, 5.80)	**5.25** (3.28, 7.22)	**6.48** (4.48, 8.47)
Launceston	75,562	1.75 (−0.63, 4.13)	1.97 (−0.40, 4.35)	2.27 (−0.11, 4.65)	0.49 (−1.89, 2.87)

Bold figures: significant at 0.05.

metropolitan city-dwellers living in small homes or apartments, migrated to regional cities seeking more space for home-based school, work, and living activities (Giles-Corti et al., 2022; Frumkin, 2021). The rapid transition to telecommuting has overcome a major deterrent for some people living in regional cities: i.e., lack of access to high-paid professional employment (Backholer et al., 2021). Hence, regional cities with good access to digital infrastructure and local amenities became very attractive to fleeing metropolitan city dwellers forced to work from home.

Without policy intervention, this trend has the potential to widen socioeconomic and health inequities in regional cities. Early research suggests that those with new-found work mobility (Delbosc and McCarthy, 2021; Nygaard and Parkinson, 2021) have the potential to reshape settlement patterns in Australia. Highly paid telecommuting white collar workers relocating to regional cities may displace lower income households, particularly those living in the liveable inner-city areas. Spikes in house prices in Australian regional cities are already evident (Terzon, 2022). If this pattern is sustained post-pandemic, it has the potential to intensify the geographic inequities in access to amenity already evident in larger Australian cities.

Given housing affordability pressures and growing inequities in cities, policies are required that ensure diverse housing forms and affordable and social housing is available throughout both metropolitan and regional cities (Sarkar et al., 2022). This includes implementing models of 'inclusionary zoning' that require affordable housing options being provided in new housing developments (Pawson et al., 2019; Gurran et al., 2018).

4.3. Reducing health inequities

The health of residents in disadvantaged areas is typically considerably poorer than their counterparts living in advantaged areas. In the Australian context, residents of disadvantaged areas are more likely to experience higher rates of morbidity and mortality for chronic disease (CVD, T2D), are more likely to be overweight and obese, and experience many other adverse outcomes (Jacobs et al., 2018; Australian Institute of Health, 2020b; Racheleet al., 2018; Rachele, Schmid, Brown, Nathan, Kamphuis, Turrell; Loh et al., 2016). Moreover, those living outside of metropolitan cities tend to have poorer health than those living in metropolitan cities (Australian Institute of Health, 2020b). Turrell et al. (Turrell et al., 2013; Turrell and Vandevijvere, 2015; Turrell et al., 2018; Loh, Rachele, Brown, Ghani, Washington, Turrell) have argued that health inequities could plausibly be reduced by creating more walkable amenity-rich areas that encourage active transport, particularly in disadvantage areas. It is possible that health inequities in regional cities would be substantially worse if lower income households are displaced from liveable inner-city neighbourhoods.

However, health inequities could be reduced by actively encouraging and supporting active transportation. Levels of active transportation for commuting are very low in Australian cities (Australian Bureau of Statistic s, 2018). With car-centric city planning and little deterrence for car use, motor vehicle dependence is very high, even in disadvantaged areas. Our results showed that in regional city neighbourhoods, an average of 60 percent of workers had access to local employment. Yet ABS census data shows that around 90 percent of regional workers travel to work by private motor vehicle (Australian Bureau of Statistics, 2018), although 30% of their work trips are less than 5 km (Australian Bureau of Statistics, 2018). This is a cyclable distance for able-bodied adults, that could be extended even further with the uptake of e-bikes (Giles-Corti et al., 2020).

In some cities throughout the world – including regional cities - political leaders have committed to sustainable mobility and are enabling sustainable development. For example, in Freiburg Germany (FitzRoy and Smith, 1998) and other European cities, investments in public transport and cycling infrastructure (Pucher and Buehler, 2008) have been prioritised, and demand for driving has been managed by restricting the movement of private motor vehicles in the inner-city and the availability of parking.

Transitioning to cities that prioritise active and sustainable mobility – particularly in more disadvantaged areas - would not only reduce in inequities and create more liveable cities, it would also produce co-benefits for individual and planetary health by encouraging physical activity, reducing exposure to air and noise pollution and mitigating climate change (Giles-Corti et al., 2022; Stevenson et al., 2016). However, this transition requires political leadership, vision and courage (Giles-Corti et al., 2022), to commit to and implement appropriate long-term policies and investments (Lowe et al., 2022).

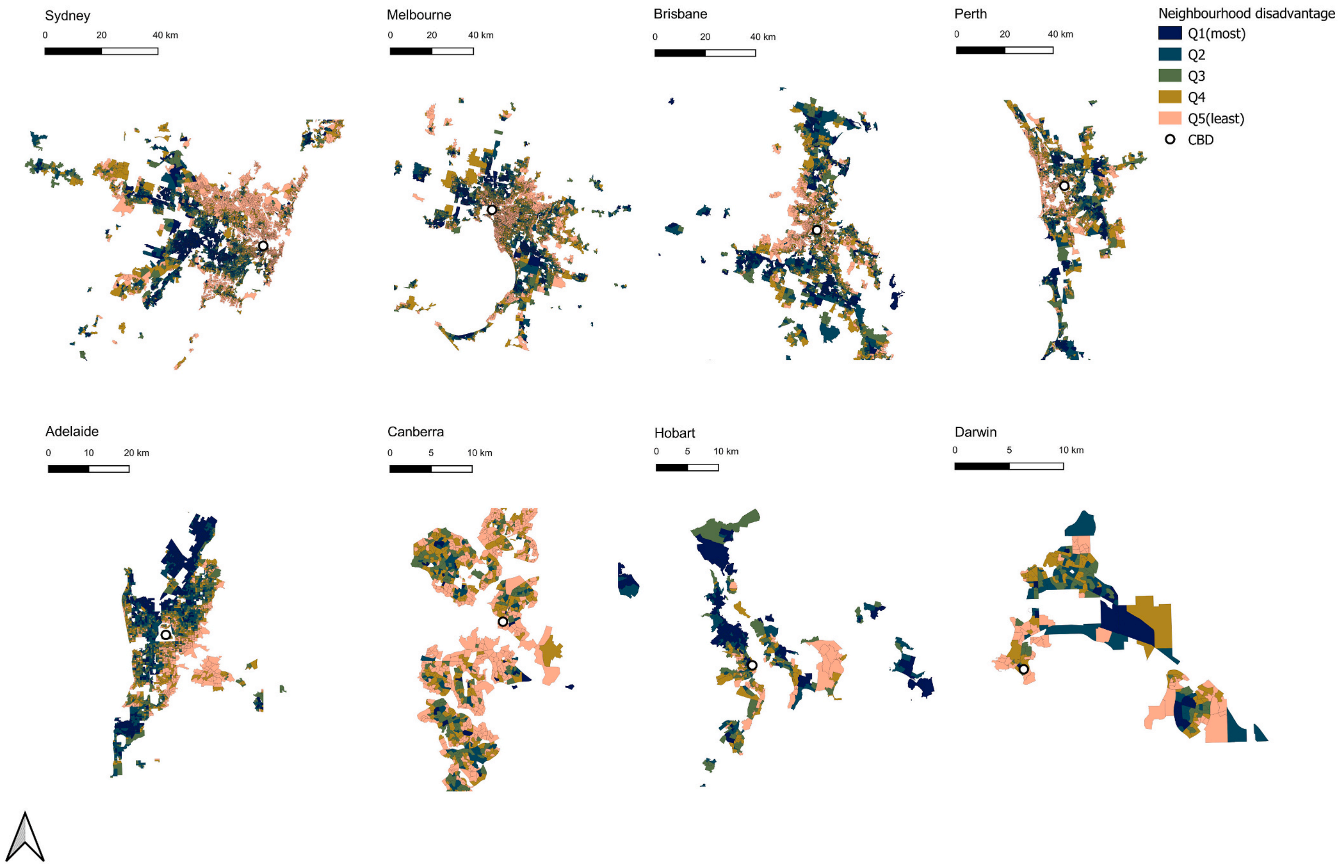


Fig. 4. Spatial distribution of neighbourhood disadvantage within Australian metropolitan cities.

4.4. *Using health-related liveability indicators to benchmark and monitor progress in cities*

This study adopted an urban liveability index comprised of indicators found to be associated with health and wellbeing. While Leach (Leach et al., 2017) has argued that the choice of indicators should be 'value free', the WHO (World Health Organization, 2016) has affirmed that health is a universal right and should be a marker of sustainable urban development, given the co-benefits across society from health and social justice policies. Hence, creating and mapping an evidence-based health-related urban liveability index provides information that can support decision-makers to achieve the aspirations of the UN SDGs (United Nations, 2018).

Some have argued that liveability means different things to different people (Balsas, 2004), noting there is little consensus about how liveability is conceptualised and measured. Moreover, in different contexts, priority may be given to different domains of liveability (e.g., access to clean water and sanitation in low-income countries where even this very basic infrastructure is not ubiquitous) (Kasim et al., 2021). In addition, liveability indicators are also often measured at different scales (e.g., urban centres (Balsas, 2004), city-wide (Valcárcel-Aguiar et al., 2019) or sub-city (Leach et al., 2017) scale). Together this makes it challenging to compare the liveability of different cities and raises question about the universality of the concept.

However, despite the diversity of measures used internationally, common themes for liveability indicators include those for basic services such as access to green space, public transport, commercial land uses, and health and community services.[120] (Khorrami et al., 2021; Alderton et al., 2019a; Basu et al., 2021; Ministry of Urban Development, 2017; Kasim et al., 2021) These are social determinants of health, and although they may look different in different contexts, they are a universal need. To compare cities—even within a country— there is a need for a core set of consistently measured indicators that can be used identify disparities. Hence, there have been calls from the UN (United Nations General Assembly, 2015; Habitat, 2017) for cities to use a common set of indicators to measure these characteristics of urban areas.

However, we would further argue that – where possible – cities should develop *spatial* indicators, to enable within-city spatial inequities to be identified (World Health Organization and UN Habitat, 2010). This is becoming much more achievable with the advent of open data (Australian Government, 2022) and the creation of tools to facilitate their development and visualisation (Liu et al., 2021; Salve et al., 2020; Australian Urban Research Infrastructure Network, 2022; Alderton et al., 2021a).

Using spatial indicators to measure and map progress in cities has the potential to meet the needs of multiple stakeholders. Depending upon the level of aggregation, spatial indicators can be used by global agencies to compare overall progress within and between countries; by national governments to set standards and make between-city comparisons (Ministry of Urban Development, 2017; Department of Infrastructure Transport Cities and Regional Development); by national, state, and local governments wishing to identify health inequities, intervene, and invest in amenities and infrastructure within cities (Australian Urban Observatory, 2020; Alderton et al., 2021b; Davern et al., 2019); by local communities to benchmark their community against others and to advocate for investments (United Way Winnipeg, 2022); and by individuals to choose where to live (AARP Public Policy Institute, 2022).

Nevertheless, creating spatial indicators using disaggregated and comparable data is not without challenges, particularly in terms of sourcing appropriate tools and data, which is often deficient in low- and middle-income countries (Liu et al., 2021). This may explain why there has been little attempt to date to recommend the use of spatial indicators in global indicator frameworks (United Nations, 2018; Habitat, 2017;

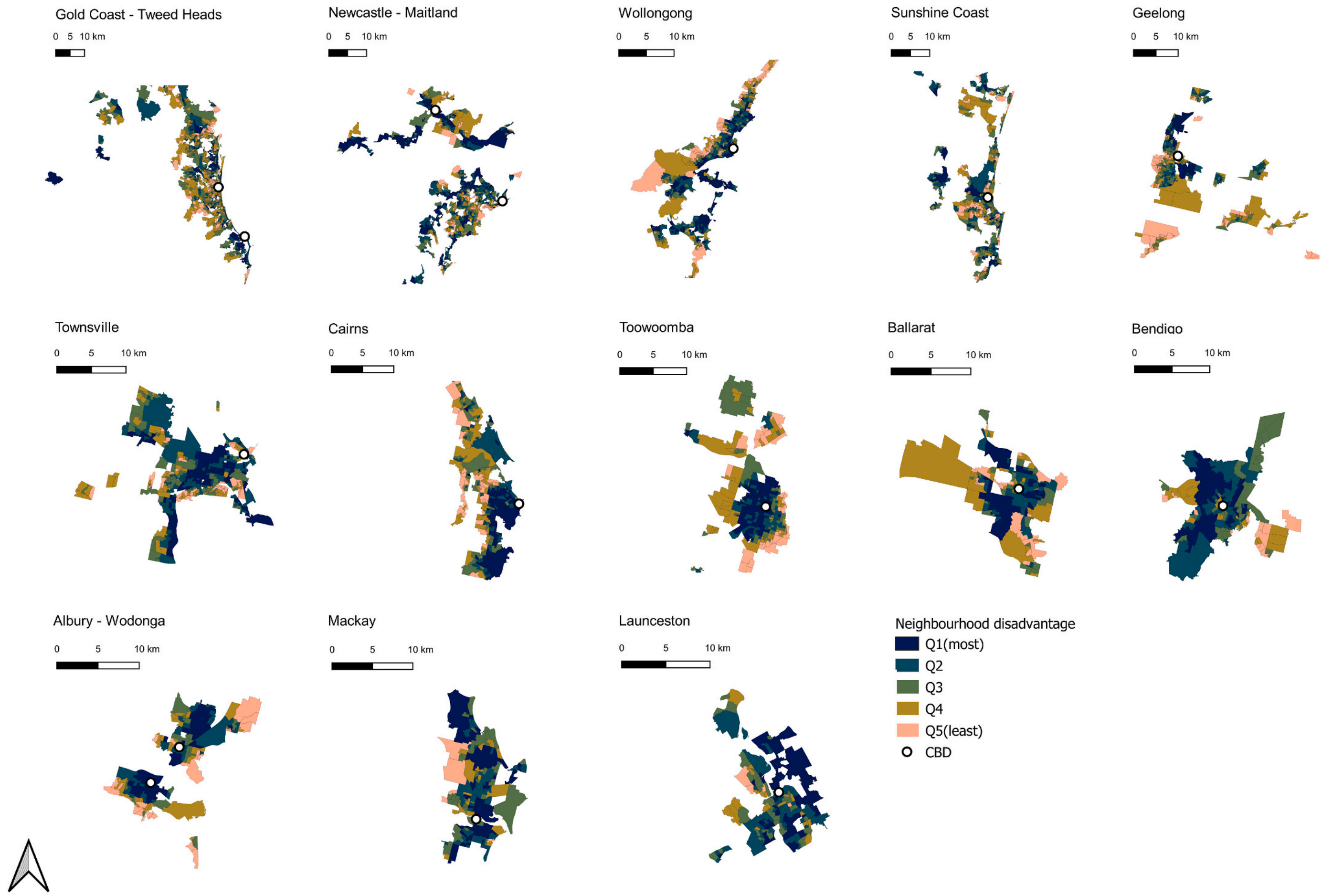


Fig. 5. Spatial distribution of neighbourhood disadvantage within Australian regional cities.

International Standards Organization, 2021). Yet despite these challenges, spatial indicators are important because they make visible the invisible, by unmasking the winners and losers within cities to help target investment (World Health Organization and UN Habitat, 2010). While some cities use surveys to ask communities to assess the quality of their own community (Scottish Government, 2022), this alone, has the potential to widen inequities due to differing expectations across socioeconomic groups. Without complementing community consultations with objective spatial measures, inequities in access to the basic services that create liveable communities may increase.

4.5. Strengths and limitations of current study

A strength of this study was that liveability domains considered (walkability and access to employment, healthy food choices, affordable housing, public open space, social infrastructure, and public transport) were based on a comprehensive, health-focused definition of liveability (Badland, Whitzman, Lowe, et al). Except for indicators that used ABS Census data for which it was necessary to use administrative boundaries, all other indicators were created based on network and spatial analysis for address point locations (see Table 1). The final selection of indicators included in our national ULI (Higgs et al., 2021). was based on those found to be associated with health and wellbeing outcomes (Badland et al., 2017a; Badland et al., 2015; Badland et al., 2017b; Badland et al., 2017c; Boulange et al., 2017; Davern et al., 2018; Feng et al., 2018; Hooper, Boruff, Beesley, Badland, Giles-Corti; Koohsari, Badland, Mavoa, et al.; Madill, Badland, Mavoa, Giles-Corti; Mavoa et al., 2018; Murphy et al., 2018a; Murphy et al., 2016; Murphy et al., 2018b; Murphy et al., 2017; Villanueva et al., 2015). Moreover, the index itself has been found to be associated with increased active transport, decreased driving (Higgs et al., 2019), and lower cardiometabolic risk factors (Higgs et al., 2021). However, our ULI does not include all domains of liveability, even those included in our original definition (Lowe et al., 2015). For example, measures of personal safety, social inclusion, and cohesion are not included, nor is a full range of health-related environmental sustainability indicators (e.g., air quality, exposure to traffic).

Omissions of environmental sustainability indicators is an important limitation, and should be addressed in future research as a matter of urgency, given a rapidly changing climate and its threat to human health (Watts and al, 2019; Watts et al., 2015). For example, in his critique of the EIU liveability index, Newton (2012) argued that an EIU 'liveable' city is not necessarily a sustainable city, and showed the substantial carbon footprint of many cities ranked as 'liveable' by the EIU. In the case of our own ULI, the omission of a measure of traffic exposure may result in a neighbourhood being rated as having highly liveable because of its health-promoting built form, but ignores that it may have poor air quality and be noisy because it has failed to manage and reduce traffic (Mueller, Rojas-Rueda, Basagana, et al.; Mueller, Rojas-Rueda, Khreis, et al.).

Several appropriate health-related environmental sustainability measures are already well-developed and suitable for inclusion in future ULIs. For example, Astell-Burt and Feng (Astell-Burt, Navakatikyan, Feng; Astell-Burt and Feng, 2020) have studied the health effects of exposure to tree canopy and found that areas with 30% or more tree canopy significantly reduces the risk of CVD and dementia. Other indicators relevant to environmental sustainability might include measures of heat island effects (Deilami et al., 2018); transport emissions; and air and noise pollution (Munzel et al., 2021). Recent research by

Martino and colleagues (Martino et al., 2021) and others (Valcárcel-Aguiar et al., 2019) provides insights into how other omitted domains, such as social inclusion, could be incorporated into future urban liveability indices.

There are several other limitations associated with the indicators used in this study. The distance thresholds adopted for different types of destinations in the liveability index, were based on policy, practice, and professional judgement at the time the index was developed. Although the index has been shown to be associated with transportation behaviours (Higgs et al., 2019), further research could identify optimal empirical distances based on population catchments for different types of destination. It could also explore whether these distance thresholds are more appropriate to achieve walkable neighbourhoods that are aligned with consumer behaviour (i.e., how far people are prepared to walk to different destinations) and to maximise the potential for active forms of transport. The index could then be adjusted accordingly. Similarly, for the public transport access indicator, we adopted a very modest frequency of service (i.e., a service every 30-min), particularly by international standards. This could be regarded as a limitation and future studies might consider more frequent public transport services (say every 10- or 20-min), as well as time spent travelling due to directness of route. Some indicators were difficult to create in the Australian context due to lack of data (e.g., the ratio of jobs/housing), and hence, we developed alternative indicators using the ABS census data (e.g., live and work in the same area). While this has led to some fruitful insights (Both et al., 2022), it did require the use of ABS census data, these data are only available at the administrative boundary level which is a limitation.

The Australian National Liveability Study was focused on developing and mapping a geospatial database of health-related liveability measures. Separately these data have been linked with other national surveys examining associations with several health and wellbeing outcomes (Alderton et al., 2019b; Villanueva et al., 2022; Higgs et al., 2022; Foster et al., 2019; Fortune et al., 2020a, 2020b). Linking urban liveability indicator data to temporally relevant national population mortality and morbidity data for relevant NCDs, would enable exploration of the extent to which area-level disadvantage contributes to objectively measured health outcomes, and the extent to which this attenuates health risks for those living in more liveable communities (Higgs et al., 2022). However, this exploration was beyond the scope of the current study. Largescale national government studies with mortality and morbidity NCD data are often only available in Australia at highly aggregated levels. Hence, linking aggregated health data and geospatial data must be approached cautiously due to the risk of ecological fallacy bias (Learnihan et al., 2011). Nonetheless, previous studies have proved informative in studying how socioeconomic disadvantage mediates the relationship between CVD mortality and the Accessibility/Remoteness Index of Australia (ARIA+) and this warrants further research, leveraging our spatial database on urban liveability (Jacobs et al., 2018), which are available on Figshare (Higgs et al., n.d) for use in other studies.

In studies of this type, there is the potential of spatial clustering to generate area-level correlations and hence non-independent observations, thus biasing the study's results. We therefore undertook a sensitivity test by analysing the association between area-disadvantage and liveability using spatial regression models for one large and one small capital city, and for one large and one small regional city. These results were compared with the regression results presented. The results and subsequent interpretations were similar irrespective of which modelling technique used. Hence, here we report the OLS regression results, which is a simpler more parsimonious model. This may be regarded as a limitation, however, the interpretability of the OLS results is also more straightforward for the reader and policymakers who we hope will use these findings.

A final strength of the current study was that it included consistent measures and data for 21 cities, and both regional and metropolitan cities. This proved important, as it highlighted that all cities are not equal; and those patterns observed – even among major metropolitan cities within one country – may vary significantly. The study highlights the value and potential of collecting local built environment and health-risk factor data to inform local policies and interventions (Giles-Corti et al., 2015).

5. Conclusion

Despite an extensive body of evidence showing how city planning decisions affect NCD risk factors and growing concern about rising sustainable development and inequities, we found that in the context of Australia's 21 largest cities, there is still much to do to achieve healthy, liveable cities for all and to avoid widening health inequities as cities grow and gentrify. Those living in outer suburban areas, have poor access to local amenity and infrastructure, although this did not always equate with socioeconomic inequities, depending upon the city's size. This study confirms the WHO's contention that all cities—even in affluent countries like Australia—have inequitable access to health-supportive amenities and infrastructure. Spatial disparities in access have important implications for global initiatives that aspire to 'leave no-one behind,' such as the UN's SDGs and New Urban Agenda.

Our findings challenge assumptions being made about where and for whom inequities exist in cities, highlighting the importance of local data to inform local decision-making, especially when comparing cities of different size and location. Our findings also highlight the need for large-scale and consistent data that allows cities to be compared. High-resolution and neighbourhood urban indicators have the potential to provide an early warning system that could be used to avoid widening inequities; to inform, benchmark and monitor policies and interventions; and inform investments and advocacy aimed at ensuring cities are healthy and liveable for all.

Conflicts of interest declaration

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Data availability

The data are available on figshare https://doi.org/10.25439/rmt.15001230.v2.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2022.102899.

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