

Review Article

The Association between Urban Form and Ischemic Heart Disease: Evidence from Brisbane, Australia

Gudes O^{1,2*}, Ball SJ³, Dur F⁴, Burke M⁵ and Varhol R⁶

¹Department of Spatial Sciences, Curtin University, Australia

²Centre for Community Science, Griffith University, Australia

³Telethon Kids Institute, University of Western Australia, Australia

⁴Environment and Sustainability Branch, Logan City Council, Australia

⁵Urban Research Program, Griffith University, Australia

⁶Department of Health Policy & Management and Health Information Management, Curtin University, Australia

*Corresponding author: Gudes O, Department of Spatial Sciences, Curtin University and Centre for Community Science, Griffith Health Institute, Griffith University, Australia

Received: January 13, 2015; Accepted: March 28, 2015; Published: March 31, 2015

Introduction

Ischemic Heart Disease (IHD) is characterised by reduced blood supply to the heart. It is one of the most common causes of mortality world-wide, resulting in 11.2% of deaths globally in 2011 [1]. In Australia, IHD accounts for 16% of all deaths [2], placing it 9th internationally in terms of contribution to national burden of disease. Major risk factors of this disease include family history of coronary artery disease, diabetes, high blood pressure or atherosclerosis, smoking, poor nutrition (especially dietary fat intake), previous heart attack or stroke, obesity, hypertension, elevated cholesterol and/or low level of High Density Lipoprotein (HDL) [3].

The built environment is highlighted as a factor determining health outcomes, as part of a broader social determinants model of health [4], yet very little is known about the effects of urban form on IHD. It has recently been proposed that urban form (the physical shape and structure of a city that influences daily activity) is an important behaviour determinant [5]. Previous studies have related urban form to travel behaviour, walking and other forms of physical activity [6,7], air pollution [8] and obesity [9,10]. These effects may be of some significance for IHD. The aim of this paper is to test for an association between urban form and the incidence of IHD in Brisbane, Australia's third largest city. We also control for the effects of age, sex, ethnicity, socioeconomic status, proximity to hospital and neighbourhood walk ability.

Methodological approach, design and settings

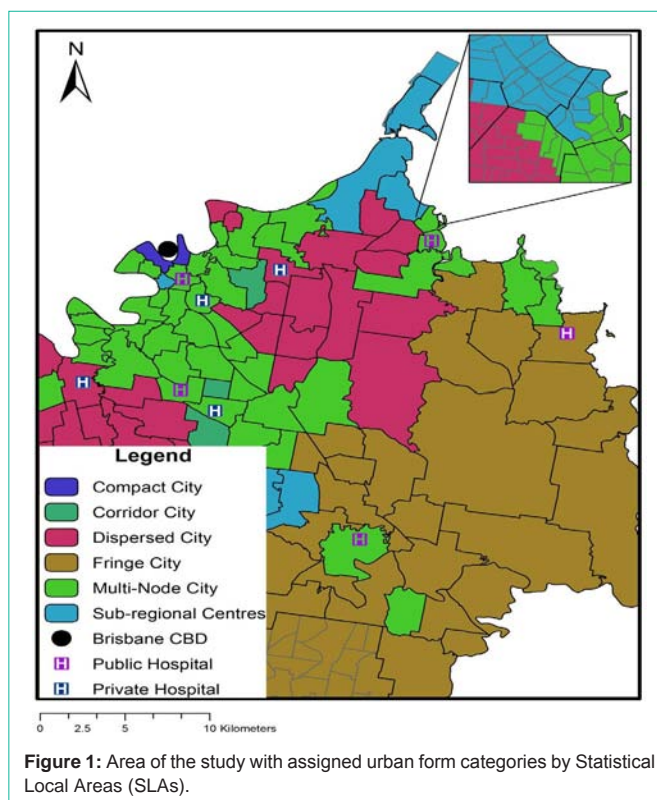
This study was a retrospective cohort study of spatial variation in the incidence of hospitalizations due to IHD in southern metropolitan Brisbane, Australia (Figure 1) from 1 January 2006 to 31 December 2011. Brisbane is the third largest city in Australia, with a population

Abstract

We measured the association between urban form and hospitalisation rates for Ischemic Heart Disease (IHD), stratified by age and sex, and controlling for ethnicity, socio economic status, proximity to hospital and neighbourhood walk ability. This was a retrospective cohort study of the proportion of people within the Brisbane area of Australia who were hospitalised between 2006 to 2011 with a primary diagnosis of IHD. There were strong spatial patterns in the incidence of IHD. The importance of predictor variables differed by sex and age. Urban form was generally not a strong predictor. This study suggests no strong relationship was identified between urban form factors and ischemic heart disease using this research approach.

Keywords: Ischemic heart disease; Urban form and structure; Spatial analysis

of 2.07 million in 2011 [11]. The spatial units were Statistical Local Areas (SLAs), as defined by the Australian Bureau of Statistics [11]. Hereafter the term “study area” refers to the 118 SLAs used for analysis (Figure 2) was based on three phases: 1.



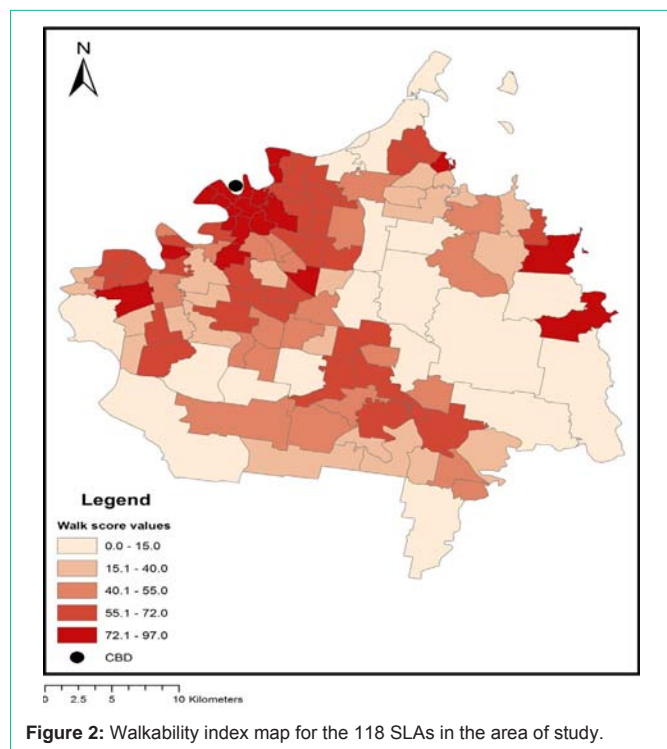


Figure 2: Walkability index map for the 118 SLAs in the area of study.

The analysis was stratified by age and sex. Our methodological approach) Adoption of methods suggested by [5, 12]. The data collection and the categories of the data aggregation were replicated by [5] within Brisbane; 2) Aggregation of the total IHD hospitalizations between 2006 and 2011 into Statistical Local Areas (SLAs) level; and 3) Bayesian modeling was undertaken in order to understand the relationships between the urban form categories and IHD hospital admission measures, which simultaneously allowed urban form to be evaluated as a risk predictor. This model also accounted for socioeconomic status, including proximity to public and private hospitals, ethnicity and walk ability index. The following sections

provide detailed information about our methodological approach, design and settings.

Urban form classification

We assigned each Statistical Local Area one of six urban form categories (Table 1), following Grosvenor and O’Neill [5]. We initially assigned this classification at the finer spatial scale of Statistical Areas Level 1 (ABS 2011) and then determined the urban form category for each SLA.

Ethnicity

The following cultural groups (categories are based on place of birth) were accounted for in the model based on the Australian Bureau of Statistics (ABS’s) main categories in 2006 [13] and 2011 [14] censuses, and the categories provided in our data set Americas, North Africa and the Middle East, North-east Asia, North-west Europe, Oceania (mostly people who were born in Australia, New Zealand, Melanesia, Micronesia, and Polynesia excluding Hawaii etc.), South-east Asia, Southern and central Asia, Southern and eastern Europe, Sub-Saharan, Africa and Not stated (Table 2).

Socioeconomic status

Socio Economic Status (SES) was based on the 2006 Australian Bureau of Statistics’ Index of Relative Socio economic Advantage/ Disadvantage [15]. This index, which is generated for each five-yearly national census, summarises the presence of both positive and negative social and economic factors (e.g. income, educational attainment and unemployment) of people and households within specific geographical areas. In deriving the Index, the Australian Bureau of Statistics used a Principal Components Analysis to assign each variable a weighting. Individual census areas are then given a score based on the sum of their variable weightings.

Neighbourhood walk ability

One way that built environment elements are organised and measured in research for active travel is with a ‘walk ability index’. One measure that has become popular in recent years is the Walk

Table 1: Urban form classification in Brisbane, Queensland (derived from: Grosvenor & O’Neill, 2012(5)).

| Urban form category | Description | GIS criteria / process |
|----------------------|---|--|
| Compact City | General increase in accessibility to public transport, employment, retail and essential services with a mixture of housing choice. | 1500m from Brisbane CBD. |
| Multi-Node City | Highly accessible to public transport, employment, retail and essential services as the Compact City but dominated by apartments. | Within 800 m of "Principal Regional Activity Centres" of South East Queensland Regional Plan (SEQRP) and within 800m proximity to railway and bus way stations |
| Sub-regional Centres | SA1 s located within 800m of railway stations (proxy for centroid) located within designated secondary centres: Sub-regional centres have similar characteristics to the Multi-Node City on a smaller scale with less employment opportunities. | SA1 s in the suburbs within 800 m buffer of "Major regional" and "Specialist" Activity Centres (See South East Queensland regional Plan 2009-2031 report) and within 800m proximity to railway and bus way stations. |
| Corridor City | Any SA1 s outside the previous categories that are located within 800m walking distance of a railway station within the rest of the metropolitan area or 400m of a high-order bus corridor. This area characterised by good accessibility to local shopping precincts with a mixture of housing choice (other than four-storey and above apartments). | SA1 within 400 m buffer of the bus stops on the road ways and major bus routes (Grosvenor & O’Neill (2012)and within 800m of railway stations which are not assigned a urban form definition category previously |
| Dispersed City | Any other areas left within what is considered the traditional Brisbane suburban environment. Generally comprises a mixture of old and contemporary detached dwellings dominated by car access and local bus services. | All SA1 s within 400m vicinity of all bus stops (from the remaining SA1s from the previous steps). |
| Fringe City | Designated areas beyond traditional suburban environments (primarily contemporary build) with poor public transport and local service accessibility. | All other SA1 s which are not selected in any previous steps |

Table 2: Proportion of people hospitalised with ischaemic heart disease as a primary diagnosis.

| 40-44 years old | | | | | | |
|------------------------------|-------------|--------------|---------------|-------------|--------------|---------------|
| | Female | | | Male | | |
| Ethnic category | Cases | Pop. | Prop. | Cases | Pop. | Prop. |
| Oceania and Antarctica | 146 | 22644 | 0.0064 | 394 | 21416 | 0.0184 |
| South-east Asia | 3 | 2103 | 0.0014 | 17 | 1530 | 0.0111 |
| Southern and Central Asia | 6 | 629 | 0.0095 | 9 | 707 | 0.0127 |
| North-east Asia | 1 | 1310 | 0.0008 | 2 | 905 | 0.0022 |
| Southern and Eastern Europe | 6 | 894 | 0.0067 | 9 | 780 | 0.0115 |
| North-west Europe | 7 | 2769 | 0.0025 | 47 | 2949 | 0.0159 |
| Sub-Saharan Africa | 2 | 879 | 0.0023 | 15 | 837 | 0.0179 |
| North Africa and Middle East | 1 | 369 | 0.0027 | 7 | 514 | 0.0136 |
| Americas | 3 | 518 | 0.0058 | 4 | 470 | 0.0085 |
| Not stated | 5 | 1576 | 0.0032 | 12 | 1794 | 0.0067 |
| TOTAL | 180 | 33691 | 0.0053 | 516 | 31902 | 0.0162 |
| 50-54 years old | | | | | | |
| | female | | | male | | |
| Ethnic category | cases | population | proportion | cases | population | proportion |
| Oceania and Antarctica | 431 | 19701 | 0.0219 | 983 | 18571 | 0.0529 |
| South-east Asia | 24 | 1893 | 0.0127 | 28 | 1394 | 0.0201 |
| Southern and Central Asia | 10 | 529 | 0.0189 | 31 | 505 | 0.0614 |
| North-east Asia | 4 | 1196 | 0.0033 | 10 | 937 | 0.0107 |
| Southern and Eastern Europe | 13 | 1127 | 0.0115 | 57 | 1120 | 0.0509 |
| North-west Europe | 51 | 2634 | 0.0194 | 109 | 2870 | 0.0380 |
| Sub-Saharan Africa | 7 | 499 | 0.0140 | 30 | 628 | 0.0478 |
| North Africa and Middle East | 3 | 161 | 0.0186 | 12 | 251 | 0.0478 |
| Americas | 11 | 461 | 0.0239 | 13 | 462 | 0.0281 |
| Not stated | 13 | 1371 | 0.0095 | 17 | 1488 | 0.0114 |
| TOTAL | 567 | 29572 | 0.0192 | 1290 | 28226 | 0.0457 |
| 60-64 years old | | | | | | |
| | female | | | male | | |
| Ethnic category | cases | population | proportion | cases | population | proportion |
| Oceania and Antarctica | 666 | 13818 | 0.0482 | 1514 | 13074 | 0.1158 |
| South-east Asia | 25 | 1070 | 0.0234 | 36 | 823 | 0.0437 |
| Southern and Central Asia | 11 | 205 | 0.0537 | 28 | 406 | 0.0690 |
| North-east Asia | 15 | 665 | 0.0226 | 25 | 601 | 0.0416 |
| Southern and Eastern Europe | 38 | 867 | 0.0438 | 97 | 1033 | 0.0939 |
| North-west Europe | 128 | 3051 | 0.0420 | 310 | 3358 | 0.0923 |
| Sub-Saharan Africa | 5 | 259 | 0.0193 | 22 | 340 | 0.0647 |
| North Africa and Middle East | 2 | 53 | 0.0377 | 15 | 101 | 0.1485 |
| Americas | 11 | 215 | 0.0512 | 20 | 374 | 0.0535 |
| Not stated | 10 | 1005 | 0.0100 | 27 | 1071 | 0.0252 |
| TOTAL | 911 | 21208 | 0.0430 | 2094 | 21181 | 0.0989 |
| 70-74 years old | | | | | | |
| | female | | | male | | |
| Ethnic category | cases | population | proportion | cases | population | proportion |
| Oceania and Antarctica | 735 | 7561 | 0.0972 | 1142 | 6209 | 0.1839 |
| South-east Asia | 33 | 515 | 0.0641 | 14 | 400 | 0.0350 |
| Southern and Central Asia | 11 | 89 | 0.1236 | 24 | 68 | 0.3529 |
| North-east Asia | 7 | 377 | 0.0186 | 21 | 379 | 0.0554 |
| Southern and Eastern Europe | 64 | 782 | 0.0818 | 122 | 795 | 0.1535 |
| North-west Europe | 136 | 1792 | 0.0759 | 287 | 1887 | 0.1521 |
| Sub-Saharan Africa | 8 | 52 | 0.1538 | 14 | 43 | 0.3256 |
| North Africa and Middle East | 9 | 24 | 0.3750 | 11 | 22 | 0.5000 |
| Americas | 6 | 57 | 0.1053 | 10 | 69 | 0.1449 |
| Not stated | 11 | 647 | 0.0170 | 9 | 614 | 0.0147 |
| TOTAL | 1020 | 11896 | 0.0857 | 1654 | 10486 | 0.1577 |

| Ethnic category | 80-84 years old | | | | | |
|------------------------------|-----------------|------------|------------|-------|------------|------------|
| | female | | | male | | |
| | cases | population | proportion | cases | population | proportion |
| Oceania and Antarctica | 906 | 5665 | 0.1599 | 783 | 3356 | 0.2333 |
| South-east Asia | 23 | 177 | 0.1299 | 15 | 93 | 0.1613 |
| Southern and Central Asia | 13 | 58 | 0.2241 | 13 | 12 | 0.9900 |
| North-east Asia | 9 | 214 | 0.0421 | 10 | 143 | 0.0699 |
| Southern and Eastern Europe | 80 | 571 | 0.1401 | 95 | 525 | 0.1810 |
| North-west Europe | 150 | 1245 | 0.1205 | 179 | 1017 | 0.1760 |
| Sub-Saharan Africa | 11 | 25 | 0.4400 | 3 | 11 | 0.2727 |
| North Africa and Middle East | 5 | 32 | 0.1563 | 8 | 15 | 0.5333 |
| Americas | 11 | 22 | 0.5000 | 8 | 22 | 0.3636 |
| Not stated | 9 | 729 | 0.0123 | 15 | 522 | 0.0287 |
| TOTAL | 1217 | 8738 | 0.1393 | 1129 | 5716 | 0.1975 |

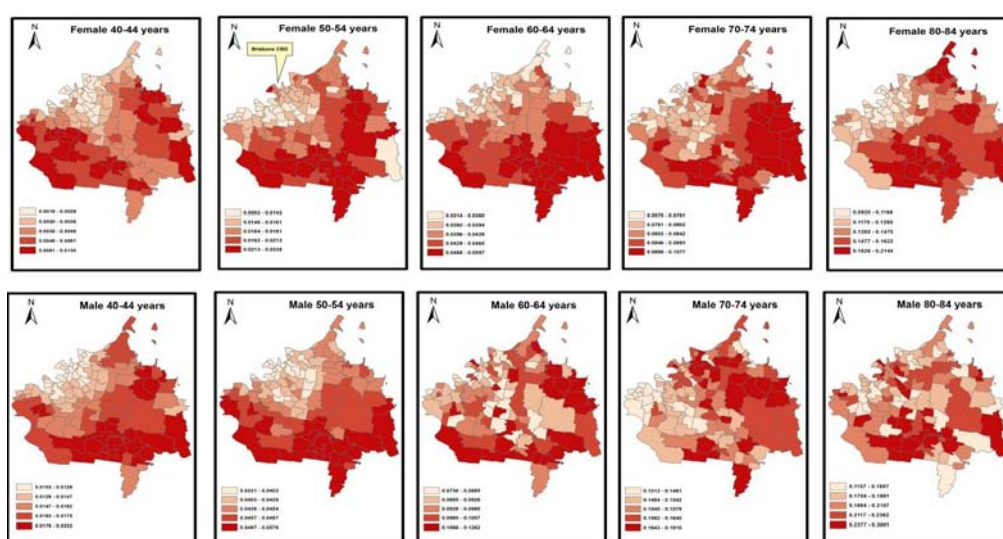


Figure 3: The Bayesian smoothed probability of IHD for each SLA stratified by age group and gender.

Score[®] [16] (<http://www.walkscore.com>) which uses Google Maps and distance-based algorithms to measure and score accessibility on foot to a range of amenities (destinations) in a certain neighbourhood. In this study we used the Walk Score website [17] to apply these metrics in our area of study. In each of the 118 SLAs we located the geographic centeroids and then extracted the associated walking score as appropriate. Figure 2 for the walk ability index by SLAs.

Distance to the nearest cardiology centre

The distance to cardiology centres (based on public and private hospitals) was identified by de An dade et al. [18] as an important measure. For example they found a positive association between IHD mortality rates and the geographic distances between patient’s city of residence and their corresponding regional cardiology centres.

Hospitalisation data

Hospitalisation data were sourced from the Queensland Health Statistics Unit, in the form of a database of hospitalisation records in the south metro Brisbane area of Queensland, dating back to 2006. For each SLA, we calculated the total number of people, stratified by age, sex and ethnicity, which had one or more hospitalisations from the first of January 2006 to the 31st of December 2011, with a primary diagnosis of IHD (ICD-10 codes I20-I25). This approach ignored

information pertaining to the number of different hospitalisation events per person, and length of stay. We restricted the analysis to people over 39 years of age given that ischemic heart disease is uncommon below 40 years [19,20], and to people under 85 years of age due to low numbers of people older than 84.

Stratification by age and sex

Stratification was undertaken by grouping the sample by age and sex to allow for demographic diversity in the spatial distribution of IHD. Such differences may arise if there are demographic discrepancies in the relative importance of different risk factors, including urban form. The population was grouped into five-year age categories given that there is a steep relationship between age and heart disease [19,20]. Further, we restricted the analysis to the first five years of every decade, so that there were a manageable number of age categories while still covering a wide distribution of ages. Thus we analysed the data for the following age categories: 40-44, 50-54, 60-64, 70-74 and 80-84 years. For each individual who had more than one hospitalisation with a primary diagnosis of ischemic heart disease in the period 2006 to 2011, we based their age category on the time of their first hospitalisation.

Population denominators

We used population census data [14] for population denominators

Table 3: Univariable and multivariable results for all urban form measures.

| Measure | Model | F40 | F50 | F60 | F70 | F80 | M40 | M50 | M60 | M70 | M80 |
|---------|-------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| URB1 | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| URB2 | Uni | 0.59 (0.10 to 4.61) | 1.14 (0.44 to 3.63) | 1.27 (0.62 to 2.8) | 1.57 (0.69 to 4.48) | 0.99 (0.53 to 1.98) | 1.4 (0.52 to 4.66) | 0.76 (0.42 to 1.43) | 0.66 (0.43 to 0.96) | 1.21 (0.69 to 2.14) | 1 (1 to 1) |
| | Multi | 0.14 (0.01 to 1.87) | 1.01 (0.29 to 4.04) | 1.04 (0.44 to 2.66) | 1.46 (0.55 to 4.4) | 0.81 (0.36 to 1.88) | 1.05 (0.35 to 3.86) | 0.6 (0.32 to 1.19) | 0.6 (0.34 to 1.11) | 1.35 (0.67 to 2.89) | 0.66 (0.3 to 1.4) |
| URB3 | Uni | 0.85 (0.26 to 6.40) | 1.18 (0.51 to 3.16) | 1.18 (0.66 to 2.44) | 1.51 (0.71 to 3.86) | 0.93 (0.54 to 1.77) | 1.38 (0.58 to 4.42) | 0.9 (0.57 to 1.57) | 0.68 (0.5 to 0.98) | 1.26 (0.78 to 2.1) | 0.55 (0.2 to 1.6) |
| | Multi | 0.23 (0.03 to 2.62) | 1.06 (0.39 to 3.98) | 1.01 (0.44 to 2.35) | 1.33 (0.52 to 3.59) | 0.73 (0.36 to 1.58) | 0.94 (0.36 to 3.23) | 0.67 (0.38 to 1.21) | 0.6 (0.38 to 0.99) | 1.43 (0.77 to 2.72) | 0.69 (0.36 to 1.35) |
| URB4 | Uni | 1.02 (0.31 to 6.89) | 1.56 (0.67 to 4.37) | 1.42 (0.81 to 2.95) | 1.94 (0.92 to 5.08) | 1.06 (0.61 to 1.99) | 1.72 (0.7 to 5.71) | 1.02 (0.65 to 1.72) | 0.78 (0.56 to 1.08) | 1.22 (0.77 to 2.02) | 0.63 (0.24 to 1.76) |
| | Multi | 0.16 (0.02 to 1.58) | 1.01 (0.33 to 3.96) | 1.17 (0.51 to 2.85) | 1.78 (0.67 to 4.79) | 0.69 (0.33 to 1.54) | 1.11 (0.41 to 3.65) | 0.66 (0.36 to 1.18) | 0.66 (0.39 to 1.14) | 1.38 (0.71 to 2.67) | 0.76 (0.4 to 1.49) |
| URB5 | Uni | 0.65 (0.19 to 4.59) | 1.22 (0.52 to 3.33) | 1.1 (0.63 to 2.21) | 1.53 (0.7 to 4.01) | 0.73 (0.41 to 1.36) | 1.2 (0.5 to 3.86) | 0.86 (0.54 to 1.49) | 0.65 (0.47 to 0.92) | 1.19 (0.74 to 2.04) | 0.67 (0.23 to 2.03) |
| | Multi | 0.18 (0.02 to 1.81) | 1.09 (0.40 to 3.91) | 0.98 (0.47 to 2.23) | 1.47 (0.58 to 3.97) | 0.6 (0.29 to 1.25) | 0.92 (0.35 to 3.06) | 0.68 (0.39 to 1.19) | 0.58 (0.36 to 0.94) | 1.33 (0.73 to 2.51) | 0.83 (0.44 to 1.62) |
| URB6 | Uni | 0.6 (0.14 to 4.51) | 1.42 (0.53 to 4.08) | 1.54 (0.81 to 3.23) | 1.65 (0.73 to 4.43) | 1.43 (0.76 to 2.59) | 2.08 (0.78 to 6.99) | 1.25 (0.75 to 2.16) | 0.76 (0.52 to 1.14) | 0.98 (0.6 to 1.76) | 0.76 (0.28 to 2.11) |
| | Multi | 0.16 (0.01 to 1.99) | 0.88 (0.27 to 3.8) | 1.13 (0.46 to 2.76) | 1.53 (0.56 to 4.5) | 0.96 (0.42 to 2.32) | 1.28 (0.45 to 4.91) | 0.84 (0.42 to 1.58) | 0.64 (0.36 to 1.12) | 1.08 (0.56 to 2.17) | 0.82 (0.39 to 1.68) |

and estimated the population denominator for each SLA, stratified by age, sex and ethnicity, as the average number of people for the 2006 and 2011 censuses [13,14]. Fractional averages were rounded to integer values, using a random number generator to determine whether to round up or down.

Statistical Analyses

$$R_i \sim \text{Binomial}(N_i, p_i)$$

$$\text{logit}(p_i) = \beta_0 \tag{1} \text{ null model}$$

where, for area i , R_i is the number of people who were hospitalised at least once for ischemic heart disease as the primary diagnosis, N_i is the total number of people of age and sex category, and p_i is the probability of being hospitalised for ischemic heart disease. The constant β_0 is the log odds of the mean probability of being hospitalised.

We used a random effects model to allow for variation between areas in the probability of ischemic hospitalisation:

$$\text{Logit}(p_i) = \beta_0 + u_i + v_i \tag{2} \text{ random effects model}$$

where u_i is a spatially-correlated random effect and v_i is a spatially-uncorrelated random effect, following [21]. The uncorrelated random effect was specified as being normally distributed with a mean of zero, and no constraint of correlation among neighbouring areas.

The spatially correlated random effect u_i was based on a Conditional Autoregressive (CAR) term, with the constraint of following a normal distribution that is conditional on the local mean of CAR random effect estimates among neighbouring areas:

$$\begin{aligned} [u_i | u_j, i \neq j, \sigma_u^2] &\sim N(\bar{u}_i) \\ [u_i | u_j, i \neq j, \sigma_u^2] &\sim N(\bar{u}_i, \sigma_i^2) \end{aligned}$$

$$\text{Where } \bar{u}_i = \frac{\sum_j u_j \omega_{ij}}{\sum_j \omega_{ij}}$$

$$\sigma_i^2 = \frac{\sigma_u^2}{\sum_j \omega_{ij}}$$

$w_{ij} = 1$ if areas i and j are neighbours; otherwise 0

Neighbours were defined as those areas immediately adjacent to the area in question, including neighbours that share only one vertex.

Standardisation for ethnicity

We used an offset term to standardise the models by ethnicity:

$$\text{logit}(p_i) = \beta_0 + \text{logit}(e_i) \tag{3} \text{ ethnically-adjusted null model}$$

and

$$\text{logit}(p_i) = \beta_0 + \text{logit}(e_i) + u_i + v_i$$

$$\tag{4} \text{ ethnically-adjusted random effects model}$$

where e_i is the expected proportion of people hospitalised in area i based on the proportion of different ethnic groups within that area, and the global (all-of-study-area) proportion of people hospitalised for each ethnic group. This standardisation was calculated separately for each age-sex demographic class (Table 2), and it shows the proportion of people hospitalised with ischemic heart disease as a primary diagnosis, by ethnic group, stratified by demographic class.

We used a mixed model to allow for the effects of urban form and other covariates, while standardising for ethnicity and allowing for spatially-correlated and spatially-uncorrelated random effects:

$$\text{legit}(p_i) = \beta_0 + \text{legit}(e_i) + \beta_1 X_1 + \dots + \beta_n X_n + u_i + v_i$$

$$\tag{5} \text{ ethnically-adjusted mixed model}$$

where $\beta_1 \dots \beta_n$ are covariate effects. We ran uni variable versions of this model, plus a full model that included effects of all covariates.

Each model was run as a Bayesian analysis. Bayesian techniques have a proven ability to solve disease mapping problems through the use of Markov Chain Monte Carlo sampling methods [23]. We specified uninformative normal prior distributions ($\mu = 0; \sigma = 1000$) for each of $\beta_0, \beta_1, \dots, \beta_n$, and following [24] we specified uninformative half-normal prior distributions ($\mu = 0; \sigma = 100$) for the standard deviation of each of the random effects u, v and d . We used Win BUGS 1.4 software [25], which uses Markov Chain Monte Carlo sampling to generate posterior distributions. For each model we used a burn-in

Table 4: Demographic groups and their associated covariate estimates that were found to be statistically significant.

| Demographic group | Covariate | Odds Ratio (95% credible interval) |
|--------------------|---------------------------------------|---------------------------------------|
| Female 40-44 years | WLK4 ^a | 0.52 (0.34 to 0.77) |
| Female 50-54 years | SES5 ^b | 0.70 (0.52 to 0.98) |
| | DISPUB (distance to public hospitals) | 0.97 (0.94, to 0.99) |
| Female 60-64 years | WLK5 ^a | 0.58 (0.42 to 0.78) |
| Female 80-84 years | SES5 ^b | 0.69 (0.54 to 0.90) |
| | WLK5 ^a | 0.73 (0.59 to 0.90) |
| Male 40-44 years | WLK4 ^a | 0.77 (0.62 to 0.94) |
| | WLK5 ^a | 0.59 (0.40 to 0.85) |
| Male 50-54 years | WLK5 ^a | 0.75 (0.59 to 0.95) |
| Male 60-64 years | URB2 ^c (Corridor City) | 0.66 (0.43 to 0.96) |
| Male 80-84 years | WLK1 ^a | 0.68 (0.51 to 0.87) |
| | WLK2 ^a | 0.80 (0.65 to 0.98) |
| | WLK4 ^a | 0.80 (0.69 to 0.94) |

^aRelative to WLK3 (reference category for walkability).

^bRelative to SES3 (reference category for socioeconomic status).

^cRelative to URB1 (reference category for urban form).

Table 5: Covariate effects for univariable and multivariable models, for all demographic categories.

| a | Model | F40 | F50 | F60 | F70 | F80 | M40 | M50 | M60 | M70 | M80 |
|--------|-------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| URB1 | Uni | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| URB1 | Multi | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| URB2 | Uni | 0.59 (0.1 to 4.61) | 1.14 (0.44 to 3.63) | 1.27 (0.62 to 2.8) | 1.57 (0.69 to 4.48) | 0.99 (0.53 to 1.98) | 1.4 (0.52 to 4.66) | 0.76 (0.42 to 1.43) | 0.66 (0.43 to 0.96) | 1.21 (0.69 to 2.14) | 0.66 (0.3 to 1.4) |
| URB2 | Multi | 0.14 (0.01 to 1.87) | 1.01 (0.29 to 4.04) | 1.04 (0.44 to 2.66) | 1.46 (0.55 to 4.4) | 0.81 (0.36 to 1.88) | 1.05 (0.35 to 3.86) | 0.6 (0.32 to 1.19) | 0.6 (0.34 to 1.11) | 1.35 (0.67 to 2.89) | 0.55 (0.2 to 1.6) |
| URB3 | Uni | 0.85 (0.26 to 6.4) | 1.18 (0.51 to 3.16) | 1.18 (0.66 to 2.44) | 1.51 (0.71 to 3.86) | 0.93 (0.54 to 1.77) | 1.38 (0.58 to 4.42) | 0.9 (0.57 to 1.57) | 0.68 (0.5 to 0.98) | 1.26 (0.78 to 2.1) | 0.69 (0.36 to 1.35) |
| URB3 | Multi | 0.23 (0.03 to 2.62) | 1.06 (0.39 to 3.98) | 1.01 (0.44 to 2.35) | 1.33 (0.52 to 3.59) | 0.73 (0.36 to 1.58) | 0.94 (0.36 to 3.23) | 0.67 (0.38 to 1.21) | 0.6 (0.38 to 0.99) | 1.43 (0.77 to 2.72) | 0.63 (0.24 to 1.76) |
| URB4 | Uni | 1.02 (0.31 to 6.89) | 1.56 (0.67 to 4.37) | 1.42 (0.81 to 2.95) | 1.94 (0.92 to 5.08) | 1.06 (0.61 to 1.99) | 1.72 (0.7 to 5.71) | 1.02 (0.65 to 1.72) | 0.78 (0.56 to 1.08) | 1.22 (0.77 to 2.02) | 0.76 (0.4 to 1.49) |
| URB4 | Multi | 0.16 (0.02 to 1.58) | 1.01 (0.33 to 3.96) | 1.17 (0.51 to 2.85) | 1.78 (0.67 to 4.79) | 0.69 (0.33 to 1.54) | 1.11 (0.41 to 3.65) | 0.66 (0.36 to 1.18) | 0.66 (0.39 to 1.14) | 1.38 (0.71 to 2.67) | 0.67 (0.23 to 2.03) |
| URB5 | Uni | 0.65 (0.19 to 4.59) | 1.22 (0.52 to 3.33) | 1.1 (0.63 to 2.21) | 1.53 (0.7 to 4.01) | 0.73 (0.41 to 1.36) | 1.2 (0.5 to 3.86) | 0.86 (0.54 to 1.49) | 0.65 (0.47 to 0.92) | 1.19 (0.74 to 2.04) | 0.83 (0.44 to 1.62) |
| URB5 | Multi | 0.18 (0.02 to 1.81) | 1.09 (0.4 to 3.91) | 0.98 (0.47 to 2.23) | 1.47 (0.58 to 3.97) | 0.6 (0.29 to 1.25) | 0.92 (0.35 to 3.06) | 0.68 (0.39 to 1.19) | 0.58 (0.36 to 0.94) | 1.33 (0.73 to 2.51) | 0.76 (0.28 to 2.11) |
| URB6 | Uni | 0.6 (0.14 to 4.51) | 1.42 (0.53 to 4.08) | 1.54 (0.81 to 3.23) | 1.65 (0.73 to 4.43) | 1.43 (0.76 to 2.59) | 2.08 (0.78 to 6.99) | 1.25 (0.75 to 2.16) | 0.76 (0.52 to 1.14) | 0.98 (0.6 to 1.76) | 0.82 (0.39 to 1.68) |
| URB6 | Multi | 0.16 (0.01 to 1.99) | 0.88 (0.27 to 3.8) | 1.13 (0.46 to 2.76) | 1.53 (0.56 to 4.5) | 0.96 (0.42 to 2.32) | 1.28 (0.45 to 4.91) | 0.84 (0.42 to 1.58) | 0.64 (0.36 to 1.12) | 1.08 (0.56 to 2.17) | 0.98 (0.34 to 3.39) |
| SES1 | Uni | 1.52 (0.81 to 2.8) | 1.58 (1.1 to 2.2) | 1.39 (1.06 to 1.87) | 1.2 (0.91 to 1.56) | 0.94 (0.7 to 1.29) | 1.8 (1.29 to 2.61) | 1.36 (1.1 to 1.72) | 1.06 (0.87 to 1.3) | 1.28 (1 to 1.64) | 0.87 (0.65 to 1.19) |
| SES1 | Multi | 1.42 (0.59 to 3.42) | 1.57 (0.99 to 2.53) | 1.35 (0.96 to 1.92) | 1.2 (0.82 to 1.79) | 0.87 (0.6 to 1.34) | 1.8 (1.22 to 2.72) | 1.29 (0.97 to 1.69) | 1.03 (0.77 to 1.33) | 1.3 (0.95 to 1.78) | 0.77 (0.45 to 1.27) |
| SES2 | Uni | 1.89 (0.82 to 4.02) | 1.25 (0.8 to 1.98) | 1.46 (1.01 to 2.03) | 1.08 (0.76 to 1.54) | 0.9 (0.63 to 1.25) | 1.29 (0.77 to 2.06) | 1.32 (0.97 to 1.76) | 1.17 (0.92 to 1.51) | 1.39 (1.02 to 1.87) | 0.96 (0.68 to 1.32) |
| SES2 | Multi | 1.71 (0.55 to 5.08) | 1.32 (0.7 to 2.55) | 1.54 (1 to 2.33) | 1.21 (0.78 to 1.89) | 0.92 (0.58 to 1.5) | 1.42 (0.8 to 2.43) | 1.3 (0.93 to 1.85) | 1.23 (0.87 to 1.71) | 1.43 (0.99 to 2.13) | 1.17 (0.7 to 2.12) |
| SES3 | Uni | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SES3 | Multi | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| SES4 | Uni | 1.15 (0.71 to 1.99) | 0.94 (0.7 to 1.27) | 0.98 (0.76 to 1.24) | 1.05 (0.82 to 1.33) | 0.87 (0.7 to 1.11) | 0.98 (0.73 to 1.34) | 0.94 (0.78 to 1.15) | 0.9 (0.77 to 1.07) | 1.19 (0.97 to 1.48) | 0.77 (0.62 to 0.98) |
| SES4 | Multi | 1.17 (0.56 to 2.56) | 0.96 (0.61 to 1.45) | 1.01 (0.72 to 1.39) | 1.07 (0.78 to 1.49) | 1.11 (0.82 to 1.54) | 1.07 (0.77 to 1.55) | 0.99 (0.78 to 1.26) | 0.86 (0.69 to 1.09) | 1.19 (0.91 to 1.58) | 0.79 (0.52 to 1.25) |
| SES5 | Uni | 0.67 (0.38 to 1.24) | 0.7 (0.52 to 0.98) | 0.86 (0.67 to 1.11) | 0.96 (0.75 to 1.23) | 0.7 (0.55 to 0.91) | 0.78 (0.57 to 1.12) | 0.83 (0.69 to 1.03) | 0.86 (0.73 to 1.02) | 1.24 (0.99 to 1.55) | 0.93 (0.74 to 1.22) |
| SES5 | Multi | 0.52 (0.21 to 1.24) | 0.71 (0.45 to 1.11) | 0.95 (0.67 to 1.33) | 1.09 (0.77 to 1.57) | 0.92 (0.69 to 1.32) | 0.89 (0.62 to 1.37) | 0.84 (0.65 to 1.08) | 0.84 (0.66 to 1.08) | 1.26 (0.95 to 1.69) | 1.03 (0.65 to 1.67) |
| DISPUB | Uni | 1 (0.96 to 1.05) | 0.97 (0.95 to 1) | 0.99 (0.97 to 1.01) | 1 (0.98 to 1.02) | 1 (0.98 to 1.02) | 1 (0.97 to 1.02) | 1.01 (0.99 to 1.02) | 1 (0.99 to 1.01) | 1 (0.98 to 1.02) | 0.98 (0.96 to 1) |
| DISPUB | Multi | 0.97 (0.88 to 1.06) | 0.98 (0.94 to 1.03) | 0.99 (0.96 to 1.02) | 1.01 (0.98 to 1.05) | 0.98 (0.95 to 1.02) | 1.01 (0.97 to 1.05) | 1 (0.98 to 1.03) | 1.01 (0.98 to 1.03) | 1 (0.98 to 1.04) | 0.99 (0.94 to 1.04) |
| DISPRV | Uni | 1.02 (1 to 1.05) | 1.03 (1.01 to 1.04) | 1.02 (1.01 to 1.03) | 1.01 (0.99 to 1.02) | 1.03 (1.02 to 1.04) | 1.02 (1.01 to 1.04) | 1.01 (1.01 to 1.03) | 1.01 (1 to 1.01) | 1 (0.99 to 1.01) | 1.01 (1 to 1.02) |
| DISPRV | Multi | 1.01 (0.94 to 1.08) | 1 (0.96 to 1.03) | 1 (0.97 to 1.02) | 1 (0.97 to 1.02) | 1.03 (1 to 1.05) | 0.99 (0.97 to 1.02) | 1 (0.98 to 1.02) | 0.99 (0.98 to 1.01) | 1 (0.98 to 1.02) | 1.02 (0.99 to 1.07) |

| | | | | | | | | | | | |
|------|-------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| WLK1 | Uni | 1.03 (0.62 to 1.55) | 0.91 (0.69 to 1.19) | 0.94 (0.72 to 1.16) | 0.87 (0.67 to 1.13) | 1.16 (0.92 to 1.53) | 0.78 (0.56 to 1.03) | 1.09 (0.92 to 1.3) | 0.97 (0.83 to 1.12) | 0.9 (0.75 to 1.09) | 0.68 (0.52 to 0.88) |
| WLK1 | Multi | 1.34 (0.63 to 2.88) | 1.14 (0.75 to 1.72) | 0.93 (0.66 to 1.32) | 0.76 (0.53 to 1.09) | 1.13 (0.79 to 1.58) | 0.81 (0.58 to 1.19) | 1.1 (0.87 to 1.38) | 0.93 (0.75 to 1.17) | 0.89 (0.68 to 1.17) | 0.5 (0.31 to 0.77) |
| WLK2 | Uni | 0.94 (0.6 to 1.48) | 0.88 (0.66 to 1.16) | 1 (0.81 to 1.2) | 0.87 (0.71 to 1.05) | 1.03 (0.84 to 1.26) | 1.05 (0.81 to 1.35) | 0.99 (0.83 to 1.18) | 0.95 (0.81 to 1.1) | 0.99 (0.84 to 1.17) | 0.8 (0.65 to 0.98) |
| WLK2 | Multi | 0.86 (0.45 to 1.63) | 0.83 (0.56 to 1.17) | 0.95 (0.71 to 1.25) | 0.83 (0.62 to 1.1) | 0.98 (0.71 to 1.29) | 1.09 (0.8 to 1.47) | 0.96 (0.8 to 1.18) | 0.91 (0.74 to 1.12) | 0.97 (0.78 to 1.21) | 0.59 (0.41 to 0.87) |
| WLK3 | Uni | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WLK3 | Multi | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| WLK4 | Uni | 0.52 (0.35 to 0.77) | 0.84 (0.68 to 1.02) | 0.96 (0.82 to 1.13) | 0.89 (0.77 to 1.05) | 0.91 (0.78 to 1.07) | 0.78 (0.62 to 0.94) | 0.93 (0.81 to 1.06) | 0.92 (0.82 to 1.03) | 0.93 (0.82 to 1.06) | 0.81 (0.69 to 0.94) |
| WLK4 | Multi | 0.59 (0.33 to 1.11) | 0.92 (0.68 to 1.25) | 0.98 (0.8 to 1.21) | 0.94 (0.75 to 1.18) | 0.9 (0.72 to 1.11) | 0.82 (0.64 to 1.06) | 0.92 (0.77 to 1.08) | 0.94 (0.79 to 1.1) | 0.98 (0.82 to 1.18) | 0.76 (0.57 to 1) |
| WLK5 | Uni | 0.57 (0.29 to 1.05) | 0.76 (0.54 to 1.07) | 0.59 (0.42 to 0.79) | 0.87 (0.68 to 1.12) | 0.74 (0.6 to 0.91) | 0.6 (0.41 to 0.85) | 0.75 (0.6 to 0.96) | 1.01 (0.85 to 1.18) | 1.03 (0.85 to 1.24) | 0.86 (0.67 to 1.11) |
| WLK5 | Multi | 0.71 (0.25 to 1.94) | 0.77 (0.45 to 1.3) | 0.64 (0.42 to 0.9) | 0.87 (0.6 to 1.25) | 0.77 (0.54 to 1.07) | 0.72 (0.47 to 1.09) | 0.81 (0.62 to 1.08) | 1.08 (0.84 to 1.41) | 1.04 (0.79 to 1.41) | 0.85 (0.54 to 1.35) |

of 1000,000 iterations, with posterior distributions generated from an additional 1000,000 iterations, thinned to 1000 samples. Convergence was confirmed using the Geweke diagnostic [26].

Findings

We identified high levels of spatial variation in the probability of IHD occurrence, which led us to examine each of the associated risk factors. For instance, Figure 3 below shows the smoothed probability of IHD incidence for each SLA stratified by age and gender. In general, the probability of being admitted with IHD for males and females between the ages of 50-54 is greater in outer suburban areas than in the inner-suburbs of Brisbane at the same time suggesting that the outlying spatial clusters are more noticeable.

Urban form was only weakly associated with the incidence of IHD (Table 3). There was no urban form categories associated with consistently high or low incidence of IHD across age and sex categories. Few other covariates had statistically significant effects on the incidence of IHD, and covariate effects were highly inconsistent

between age and sex categories (Tables 4 & 5).

There were generally strong patterns of residual spatial variation after accounting for the combined effects of urban form, ethnicity, socioeconomic status, walk ability and distance to local hospitals. Figure 4 shows the odds ratios (residual variation) from the fully adjusted model versus the odds ratios from random effects model (model that did account for the covariates) [bottom]. The findings suggest that after accounting for the covariates, the inter quartile difference between the demographic categories decreases (smaller inter quartile range). For instance, before accounting for the covariates within the Male 50-54 age group (Odds of IHD hospitalisation), the inter quartile ranges were between 0.89 to 1.14. After accounting for the covariates, the inter quartile ranges for the same groups were between 0.97 to 1.05, see also (Figure 5). We can therefore surmise from these findings that after accounting for the covariates the inter quartile differences between demographic groups were predominantly more noticeable for male's between 50-54 and 40-44 years of age, spatial pattern identified the odds of IHD

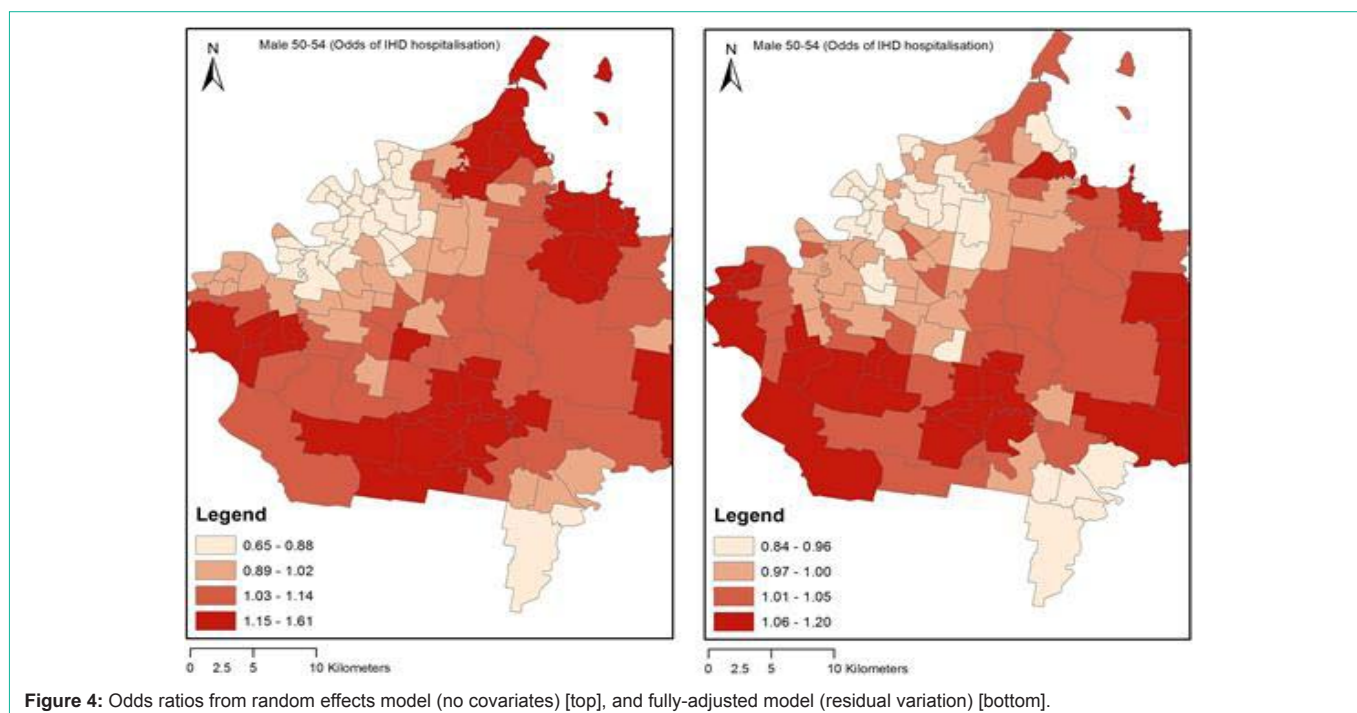


Figure 4: Odds ratios from random effects model (no covariates) [top], and fully-adjusted model (residual variation) [bottom].

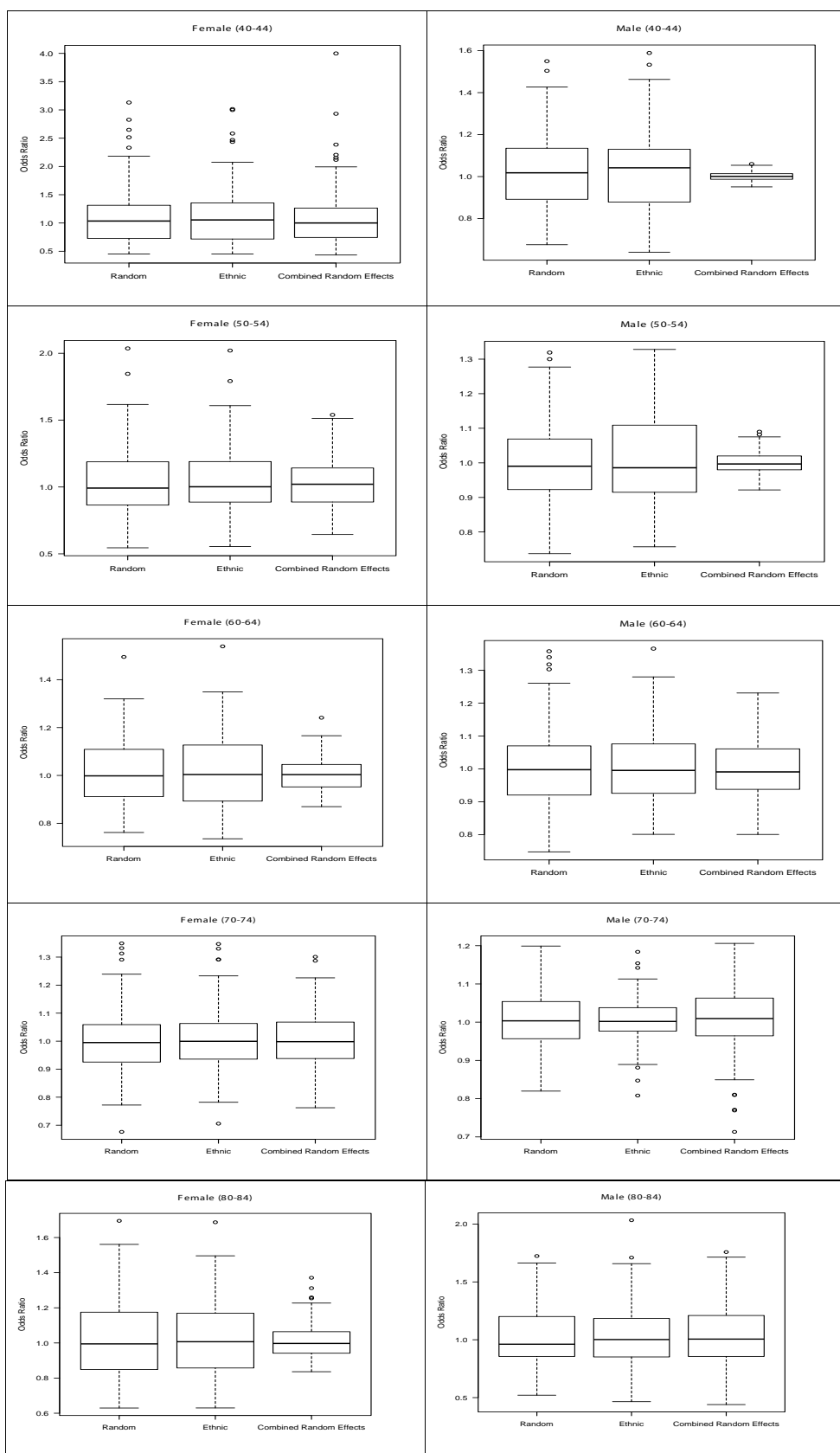


Figure 5: Box plots diagram that shows the interquartile range of odds ratios across the age and sex categories.

hospitalisations for 60-64 year old males were significantly greater in outer suburban areas compared to the inner-suburbs of Brisbane.

Discussion, Limitations and Future Research

A result of urban or semi urban characteristics of our area of interest. This however, remains to be investigated further. In this study, the principal aim was to test for a relationship between urban form and IHD; the results suggest that urban form was not a strong predictor of IHD. In fact, the covariates did little to explain the variation between SLAs, with the exception of 60-64 year old men demographic category. Even with this finding, albeit marginal, there was little additional evidence of an effect of urban form on the incidence of ischemic heart disease. It may be that similar to past attempts to identify the impacts of urban form, these differences are very small or it may be that there better ways to measure urban form. For instance, de Andrade et al. [18]. Suggest that the high mortality rate of IHD within regional areas were dependent on the distance between each city and their reference interventional cardiology centre, which implies that distance to hospital may be a potential confounder. However, in our study we did not find strong evidence pertaining to distance, which may be as strong patterns of spatial variation in IHD have been observed in the study. Spatial variation has been tested after taking multiple risk factors into account. There were generally strong patterns of residual spatial variation in IHD after taking into account the covariates. For example, patterns of spatial variation in the rates of IHD can be seen in women aged 40-44 years of age with higher incidences of hospitalisation on either side of the multi-node corridor. However with the increase in age, women in the study area were more likely to be hospitalised in the fringe city region than the dispersed city category, reasons for that were left unanswered.

The effects of other covariates were generally weak and inconsistent between demographic categories. For instance, different demographic categories showed different amounts of spatial variation and different relationships within the covariates. It appeared that after controlling for socioeconomic status and other covariates, the urban form variables were not associated with strong effects of IHD hospitalisation. The improved model simply did not reveal a sufficient difference.

Several limitations must be considered in this study. In general, the study did not reveal why IHD may have a relationship to urban form. It was found that the effect of most covariates was generally weak, but there were some effects that varied between demographic categories, which may require further investigation. Therefore, we were not able to make any firm conclusions about why or whether a particular set of covariates was important for a particular demographic group. Also, for some demographic groups, there was a decrease in residual variation (e.g., male 50-54 and male 40-44), after including all covariates in the model. This is an important finding, since it creates an opportunity for further investigation focused on these two age groups. The potential of limitations of geographic scale which constrained the study to an aggregated SLA level as opposed to the more detailed SA1 (statistical Area Level 1), may have been more suitable scale and may have yielded higher spatial resolution. Other limitations that were found in our dataset were those related to

the type of datasets being assembled and some of the measures used in the covariates. With regards to some of the measures used in the covariates, the Walk Score data that was used ignores topography, urban design measures (other than those that affect networks and distances such as 'connectivity' etc.) and in Australia has a reduced level of information than in US cities, which could have limited its utility. Also, the fact that we used centroids to represent a large area of SLAs rather than specific location reduces its reliability as SLAs can vary spatially in its walk ability level, especially if they are large areas. In Summary, this study was pioneering in its nature and perhaps is one of the first attempts in the literature to test the relationship between urban form and IHD and health measures in general. More research will be required to address the unanswered questions raised (e.g., better way to measure urban form or the findings associated with the 40-44, 50-54 male group) in this study and may constitute a new avenue for future studies in this domain.

Acknowledgment

We thank Dr Geoff Morgan (University of Sydney) and Dr Rosemary Wyber (Telethon Kids Institute) for initial discussions about types of heart disease to focus on. We also would like to thank the following organisations who made this study possible:

- Queensland Health Statistics unit
- Queensland Health
- Griffith Health Institute; Griffith University

References

1. WHO. The top 10 causes of death. 2013.
2. AIHW. Australia's health 2012. Canberra: Australian Institute of Health and Welfare. 2012.
3. Blessey R. Epidemiology, Risk Factors, and Pathophysiology of Ischemic Heart Disease. *Phys Ther.* 1985; 65: 1796-1805.
4. Schulz A, Northridge ME. Social determinants of health: implications for environmental health promotion. *Health and Education Behaviour.* 2004; 31: 455-471.
5. Grosvenor M, O'Neill P. Exploring the relationship between urban form and sustainable household behaviour. 2012.
6. Badland HM, Oliver M, Kearns RA, Mavoa S, Witten K, Duncan MJ, et al. Association of neighbourhood residence and preferences with the built environment, work-related travel behaviours, and health implications for employed adults: Findings from the URBAN study. *Social Science & Medicine.* 2012; 75: 1469-1476.
7. Frank LD, Schmid TL, Sallis JF, Chapman J, Saelens BE. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ. *American Journal of Preventive Medicine.* 2005; 28: 117-125.
8. Schwela D. Air Pollution and Health in Urban Areas. *Reviews on Environmental Health.* 2000; 15: 13-42.
9. Garden F, Jalaludin B. Impact of Urban Sprawl on Overweight, Obesity, and Physical Activity in Sydney, Australia. *Journal of Urban Health.* 2009; 86: 19-30.
10. Lopez RP. Neighborhood Risk Factors for Obesity. *Obesity.* 2007; 15: 2111-2119.
11. ABS, cartographer Australian Statistical Geography Standard 2011. Queensland Statistical Areas - Level 1 (SA1), 2011 (within SA2). Australia: Australian Bureau of Statistics. 2011.
12. Newton P. Urban Form and Environmental Performance. Jenks M, Williams

- K, Burton E, editors. In: Achieving Sustainable Urban Form. London, New York: E & FN Spon. 2000; 46-53.
13. Census Collection District by Country of Birth of Person, Age 5 Year Age Groups and Sex, Queensland. Australian Bureau of Statistics. 2006.
14. Census QuickStats. 2011.
15. Australian Bureau of Statistics. 2039.0 Information Paper: An Introduction to Socio-Economic Indexes for Areas (SEIFA), 2006. 2008.
16. Walk Score. 2014.
17. Babb C, Burke M, Tranter P. Developing neighbourhood 'walkability' indices for children's active transport. Healthy Cities and Planning - 3rd World Planning Schools Congress. 4-8 July Perth (WA) 2011.
18. de Andrade L, Zanini V, Batilana AP, de Carvalho ECA, Pietrobon R, Nihei OK, et al. Regional disparities in mortality after ischemic heart disease in a Brazilian state from 2006 to 2010. *PloS one*. 2013; 8.
19. Dobson AJ, Gibberd RW, Wheeler DJ, Leeder SR. Age-specific trends in mortality from ischemic heart disease and cerebrovascular disease in Australia. *Am J Epidemiol*. 1981; 113: 404-412.
20. Finegold JA, Asaria P, Francis DP. Mortality from ischaemic heart disease by country, region, and age: Statistics from World Health Organisation and United Nations. *Int J Cardiol*. 2013; 168: 934-945.
21. Besag J, York J, Mollie A. Bayesian image-restoration, with two applications in spatial statistics. *Annals of the Institute of Statistical Mathematics*. 1991; 43: 1-20.
22. Best N, Richardson S, Thomson A. A comparison of Bayesian spatial models for disease mapping. *Stat Methods Med Res*. 2005; 14: 35-59.
23. Lawson AB. Disease map reconstruction. *Stat Med*. 2001; 20: 2183-2204.
24. Gelman A. Prior distributions for variance parameters in hierarchical models. *Bayesian Analysis*. 2006; 1: 515-534.
25. Lunn DJ, Thomas A, Best N, Spiegelhalter D. WinBUGS - A Bayesian modelling framework: Concepts, structure, and extensibility. *Statistics and Computing*. 2000; 10: 325-37.
26. Geweke J. Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. Bernardo JM, Berger, Dawid AP, Smith JFM, editors. In: *Bayesian Statistics 4*. Oxford University Press; 1992; 169-193.