New Zealand Population Review, Special Issue

Construction of a Consistent Historic Time-Series Area-Level Deprivation Metric for Aotearoa New Zealand

BINGYU DENG,[*] MALCOLM CAMPBELL,[†]
GERALDINE F. H. MCLEOD,[‡] JOSEPH BODEN,[§]
LUKÁŠ MAREK,[**] CLIVE E. SABEL,[††]
PAUL NORMAN,[‡‡] AND MATTHEW HOBBS[§§]

Abstract

[*] Susie (Bingu) Deng is a PhD student in geospatial science and public health at the Faculty of Health | Te Kaupeka Oranga and the GeoHealth Laboratory | Te Taiwhenua o te Hauora, both at the University of Canterbury | Te Whare Wānanga o Waitaha. Corresponding author: bingyu.deng@pg.canterbury.ac.nz

[†] MalcolmCampbell is an associate professor in quantitative human geography at the University of Canterbury (UC) | Te Whare Wānanga o Waitaha. He is the current director of the GeoHealth Laboratory at UC and the founder of the Regional Analytics Lab.

[‡] Geraldine McLeod was formerly a senior research fellow in the Christchurch Health and Development Study at the University of Otago | Te Whare Wānanga o Ōtākou, Christchurch.

[§] Joseph Boden was the former director of the Christchurch Health and Development Study at the University of Otago | Te Whare Wānanga o Ōtākou, Christchurch.

[**] Lukáš Marek is a postdoctoral researcher in spatial and spatio-temporal analysis at the GeoHealth Laboratory at the University of Canterbury | Te Whare Wānanga o Waitaha.

[††] Clive Sabel is a professor of spatial science, health and the environment at Aarhus University, Denmark. He is also the director of the BERTHA Big Data Centre for Environment and Health at Aarhus University.

[‡‡] Paul Norman is an associate professor specialising in population and health geography at University of Leeds, UK.

[§§] Matthew Hobbs is a senior lecturer in health sciences at University of Canterbury | Te Whare Wānanga o Waitaha. He is also a co-director of GeoHealth Laboratory at UC and Susie's senior PhD supervisor.

Few metrics of area-level socioeconomic deprivation exist that are comparable over time and space. This study aimed to create a consistent historic time-series area-level deprivation metric for 1981, 1986 and 1991 in Aotearoa New Zealand (hereafter, New Zealand) using census data at census area unit (CAU) level. Consistent variables, geography and statistical methods were employed over time. The metric revealed a gradual worsening of area-level deprivation in NZ from 1981 to 1991. We provide a historical perspective on New Zealand's socioeconomic conditions during the 1980s and early 1990s, which provides a platform for longitudinal studies in New Zealand to account for historical area-level deprivation.

Keywords: area-level socioeconomic status; deprivation; historical; GIS; New Zealand

Whakarāpopotonga

Susie (Bingyu) Deng is a PhD student in geospatial science and public health at the Faculty of Health | Te Kaupeka Oranga and the GeoHealth Laboratory | Te Taiwhenua o te Hauora, both at the University of Canterbury (UC) | Te Whare Wānanga o Waitaha. Corresponding author: bingyu.deng@pg.canterbury.ac.nz
Malcolm Campbell is an Associate Professor in quantitative human geography at UC. He is the Director of the GeoHealth Laboratory at UC and the founder of the Regional Analytics Lab.
Geraldine McLeod was formerly a senior research fellow in the Christchurch Health and Development Study (CHDS) at the University of Otago | Te Whare Wānanga o Ōtākou, Christchurch.
Joseph Boden is a Principal Scientist in the CHDS at the University of Otago | Te Whare Wānanga o Ōtākou, Christchurch.
Lukáš Marek is a Research Fellow in spatial data science at the GeoHealth Laboratory at UC.
Clive Sabel is a Professor of Big Data and Spatial Science at University of Plymouth, UK. He is also the Director of the BERTHA Big Data Centre for Environment and Health at Aarhus University, Denmark.
Paul Norman is an Associate Professor specialising in population and health geography at University of Leeds, UK.
Matthew Hobbs is a Senior Lecturer (above the bar) in public health at UC. He is also co-director of GeoHealth Laboratory at UC.

While the concept of deprivation lacks a clear-cut definition (Carstairs & Morris, 1989), it is widely accepted that *deprivation* generally denotes a state of disadvantage in comparison with the surrounding community or the larger society or nation to which an individual, family, or group belongs (Townsend, 1987). In the literature, this state of disadvantage is also known as *neighbourhood socioeconomic status* (Murakami et al., 2009) or *social inequality* (Barbek et al., 2022). Several metrics have been devised to quantify deprivation at the level of small geographic areas. Some of the earliest examples from the UK include the Townsend Deprivation Index (Townsend, 1987), the Carstairs Index (Carstairs & Morris, 1990), and the Jarman Index (Jarman, 1991). The Townsend Deprivation Index has served as the basis for several subsequent area-level deprivation metrics (Exeter et al., 2017). It measures material deprivation based on four indicators: unemployment, non-home ownership, overcrowding and non-car ownership (Townsend, 1987). However, more contemporary area-level deprivation metrics, such as the Index of Relative Socio-economic Disadvantage from Australia (Australian Bureau Of Statistics, 2021) and the Area Deprivation Index from the United States (Kind & Buckingham, 2018), have expanded the scope of deprivation beyond material factors to measures of wellbeing, such as education. Furthermore, other area-level metrics have taken a more comprehensive approach, incorporating environmental factors like accessibility to services (e.g., medical facilities) and information on the environment (e.g., crime rates, air quality, flood risk, green space) (Allik et al., 2020; Exeter et al., 2017). Overall, many metrics have been devised that summarise socioeconomic disadvantage; however, they often provide only a snapshot of the conditions at a specific point in time.

Area-level deprivation metrics have been used extensively in the social and health sciences for research and policy development. By providing information on socioeconomic

disadvantage and inequalities over space, and sometimes time, these metrics have become crucial tools for the creation of evidence-based policy (Norman, 2010, 2016; Pratschke & Haase, 2015). For example, using area-level deprivation as a weighting factor in funding allocation makes it possible to ensure that resources such as funding for schools and health organisations are directed towards areas of high need (Exeter et al., 2017; Salmond & Crampton, 2012). In addition, these metrics are highly valued in research in social and public health as they can be used as both a variable of interest and a confounding variable (Salmond & Crampton, 2012), helping researchers gain insights into the underlying causes or potential outcomes of the inequalities in area-level deprivation (Pampalon et al., 2012). For instance, previous research has found that area-level deprivation is associated with health outcomes including obesity (Adams et al., 2009), mental health conditions (Cairns et al., 2017; Skapinakis et al., 2005), reduced life expectancy (Tobias & Cheung, 2003), and lower health-related quality of life (Adams et al., 2009). Overall, knowledge of area-level deprivation can inform the development of policies and research aimed at reducing these inequalities and improving the overall wellbeing of communities.

Aotearoa New Zealand (hereafter, New Zealand) has two widely used deprivation metrics: the *New Zealand Deprivation Index (NZDep)* (Atkinson et al., 2019) and more recently, the *New Zealand Index of Multiple Deprivation (NZIMD)* (Exeter et al., 2017). The NZDep used census data that was collected every five years from 1991 to 2018. The NZDep 1991 encompassed seven domains of deprivation: income, transport, living space, home ownership, employment, qualifications and social support (Crampton et al., 1998). Changes in domains have occurred in different versions of the NZDep, such as the addition of ‘access to telephone’ in the NZDep 1996 (Salmond et al., 1998) and the removal of the ‘transport’ domain in the latest NZDep 2018 (Atkinson et al., 2019). The NZDep used meshblock as the smallest geographic until the 2018 Census, when the NZDep

was presented at both Statistical Area 1 (SA1) and meshblock levels (Atkinson et al., 2014; Crampton et al., 1998; Salmond & Crampton, 2002; Salmond et al., 2007; Salmond et al., 1998). A meshblock contains around 90 people per area (Crampton et al., 1998), while a SA1 contained 100–200 residents per area in 2018 (Atkinson et al., 2019). In contrast, the NZIMD draws on multiple data sources, including not only census data but also data from administrative sources such as the Ministry of Health, Stats NZ and the Ministry of Social Development (Exeter et al., 2018; Exeter et al., 2017). The NZIMD measures seven domains of deprivation: employment, income, crime, housing, health, education and geographical accessibility of facilities. The NZIMD was developed in 2013 and again in 2018, with slight modifications to the variables within each domain to better reflect social advancement. It utilises data zones as the geographic boundary, with an average population of 712 in 2013 and 761 in 2018. An advantage of the NZIMD is its flexibility, allowing the use of individual domains, or combinations thereof, for different scenarios.

Although the NZIMD and NZDep have been used in many studies in New Zealand, inconsistencies across different versions of these indices have hindered their use in longitudinal studies that require consistent measures of deprivation over time. This is because the forms of the questions and the geographic boundaries across censuses may vary through time, making a deprivation score calculated for one area in one census not directly comparable with a score from another census year (Norman, 2010). Furthermore, the statistical methods and weights employed for constructing these area-level deprivation metrics may also change. To enable the use of area-level deprivation metrics in longitudinal studies, an area-level deprivation metric with consistent geographical boundary data, definition of variables, and statistical methods of construction must be established (Salmond & Crampton, 2012). In a systematic review conducted by Jivraj et al. (2020), which examined 53 studies on life course exposure to neighbourhood

deprivation and its impact on health and wellbeing, only 6 per cent of the studies measured the neighbourhood deprivation retrospectively, using historical census data linked to individuals' residential life history. In addition, only 30 per cent of studies explicitly mentioned the use of consistent geographic boundaries over time by redistributing neighbourhood deprivation data from earlier and later time points (Jivraj et al., 2020). In short, these inconsistencies in the measures of area-level deprivation employed in existing longitudinal studies have complicated the establishment of causality between area-level deprivation and health or wellbeing.

In New Zealand, the development of an area-level deprivation metric with historical and time-series data is useful for several reasons. First, it can provide insights into how area-level deprivation has evolved over both time and space. By understanding these patterns, policymakers and researchers can identify areas that require more attention and resources to address systemic issues related to deprivation and inequality (Diaz et al., 2021; Singh, 2003; Tobias & Cheung, 2003). Second, by analysing data over an extended period, researchers can identify factors that have contributed to the current state of deprivation in certain areas, such as socioeconomic policies and historical events (Exeter et al., 2019; Fu et al., 2015). And finally, the availability of a longitudinal area-level deprivation metric can enable New Zealand-based longitudinal research in social and public health areas to link past exposure to area-level deprivation to long-term health and behaviour outcomes (Baranyi et al., 2022; Jivraj et al., 2020). Research has demonstrated the noteworthy influence of area-level deprivation on outcomes after isolating the influence of individual-level or family-level deprivation, such as all-cause mortality (Ribeiro et al., 2022) and self-harm and violent criminality (Ejlskov et al., 2023), highlighting the importance of incorporating area-level deprivation measures in social and health research in addition to traditional individual-level or family-level deprivation. To address the historical gap before 1991 regarding area-level

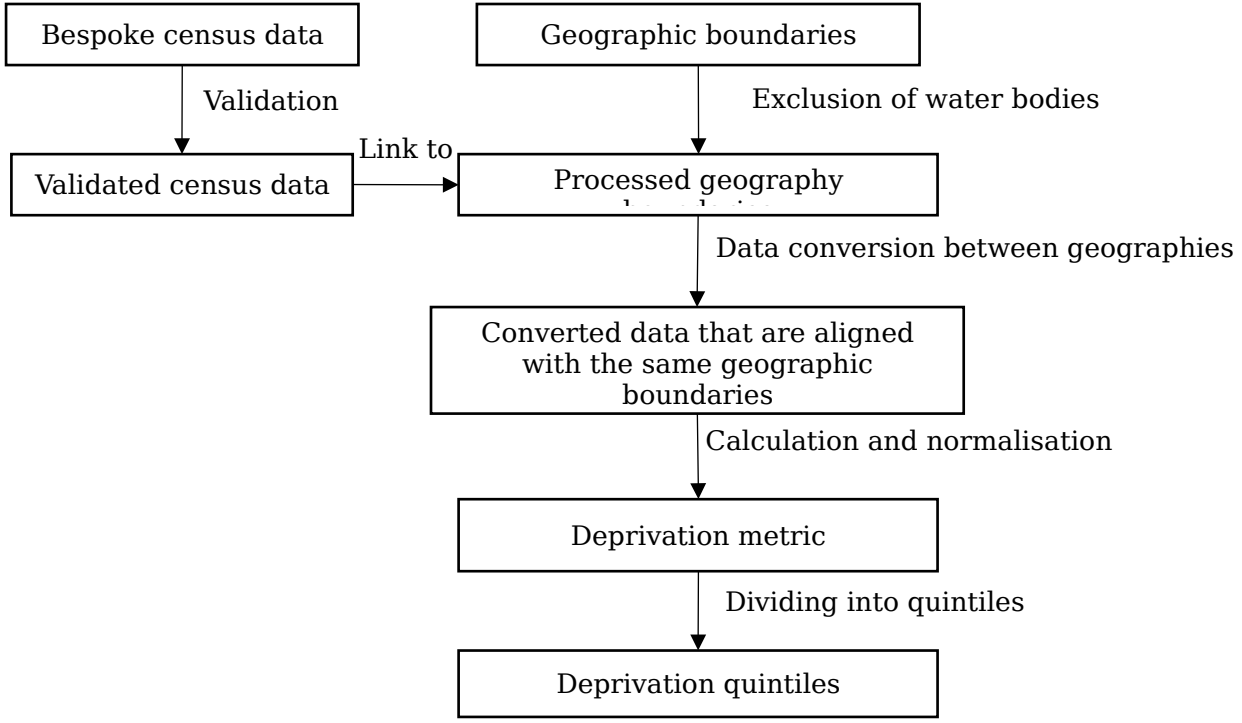
socioeconomic conditions in New Zealand, this study aimed to create a time-series area-level deprivation metric for New Zealand in 1981, 1986 and 1991. Unlike existing indices that measure relative socioeconomic deprivation, this study focused on measuring absolute changes in socioeconomic deprivation, specifically through the proportions of unemployment and non-home ownership. The study also visualised the time-series area-level deprivation metric and compared the changes in area-level deprivation over time and space.

Methods

An overview

The workflow of constructing the area-level deprivation metric in this study is illustrated in Figure 1. Bespoke census data on the Work and Labour Force Status (WLFS) of individuals and tenure status of dwellings by census area unit (CAU) and corresponding geographic boundaries in 1981, 1986 and 1991 were requested from Stats NZ. The 1981 census year was the earliest time-point that census data with valid geographic boundaries were available. The data sources and processing steps involved in handling the raw census and geography data are described in the subsection ‘Geography data’. Following the linkage of census data to their respective geography data, the data from 1981 and 1986 were aligned with the geographic boundaries used in 1991. The conversion of data between different geographic boundaries is detailed in the subsection ‘Converting data between geographic boundaries’. After conversion, the percentages of unemployment and non-home ownership were calculated and then normalised using a median absolute deviation (MAD) transformation across the different census years. The resulting area-level deprivation scores were then divided into quintiles. The specific details of each step are outlined in the subsection ‘Calculating and constructing the area-level deprivation metric’.

Figure 1: Workflow of constructing the time-series area-level deprivation metric

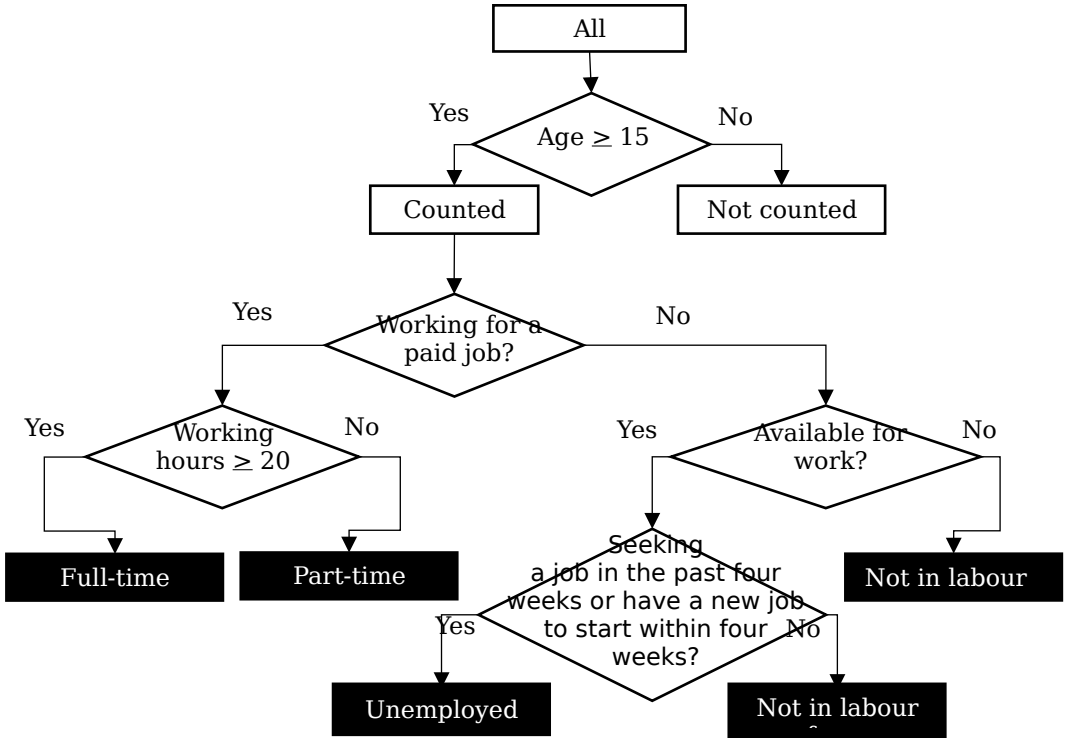


Data sources

Census data

Work and Labour Force Status (*WLFS)* data provide information on the employment status of individuals aged 15 years and over on the census night. While the categorisations of WLFS vary across the three censuses, the data for 1981 and 1986 were counted using the 1991 definition of WLFS to ensure comparability between different census years. Relevant evidence on how the WLFS questions were asked in the three censuses can be found in the supplementary notes.[1] In this study, our data for the WLFS status are divided into four categories: 1) full-time employed, 2) part-time employed, 3) unemployed, and 4) not in the labour force. Figure 2 illustrates the criteria used to classify individuals into these categories of WLFS in the 1991 Census. The 'unemployed' and 'not in the labour force' categories were used in the subsequent calculation of the unemployment percentage (as the unemployment percentage is defined as the proportion of unemployed individuals in the economically active population). Specifically, *unemployed people* are defined as individuals who meet all the following criteria: 1) they are 15 years of age or older, 2) they are not currently employed in a paid job, and 3) they have either been actively seeking employment within the past four weeks or have secured a new job to start within the next four weeks. Individuals who are *not in the labour force* apply to two categories: 1) those who are not currently employed in a paid job and are also not available for work, and 2) those who are not currently employed in a paid job, are available for work, but have not actively sought employment within the past four weeks or do not have a new job to start within the next four weeks.

Figure 2: Definition of work and labour force status (WLFS) in the 1991 Census



The *dwelling tenure* data provide information on the occupancy status of private dwellings on the census night. The categorisations of occupancy status again varied across the three censuses. Relevant evidence on how the occupancy status of private dwellings was obtained in the three censuses can be found in the supplementary notes. There were six categories of dwelling tenure in the 1981 Census: 1) owned with a mortgage, 2) owned without a mortgage, 3) rented or leased but not from the employer of the tenant, 4) rented or leased from the employer of the tenant, 5) provided free but not with a job, and 6) provided free with a job. Of these categories, categories 3 and 4 were considered private dwellings that are not owned by the occupants. In the 1986 and 1991 censuses, the six categories from the previous census were simplified into four: 1) owned with a mortgage, 2) owned without a mortgage, 3) rented or leased, and 4) provided free. Of these categories, category 3 was considered private dwellings that are not owned by the occupants. In addition, the dwelling tenure data also include an "unspecified column indicating the number of private dwellings with unknown occupancy status".

Geography data

Geographic boundaries in this deprivation metric are defined on the CAU level, which was the second smallest statistical area in New Zealand Standard Areas Classification 1992 (Department of Statistics New Zealand, 1992). The smallest statistical area is meshblock (Department of Statistics New Zealand, 1992). CAUs are created by aggregating adjacent meshblocks that share contiguous boundaries, making them intermediate in size between meshblocks and territorial authorities (Department of Statistics New Zealand, 1992). The size of CAUs can vary depending on whether they are in urban or rural areas and over time as areas change in their population structure and urban form, but CAUs are typically collections of city blocks in urban areas and similar in size to localities or communities in rural areas (Department of Statistics New Zealand, 1992). Each CAU

has a unique name and identifier and is a distinct geographic entity (Department of Statistics New Zealand, 1992). CAUs were chosen in this metric instead of meshblocks because data from the 1981, 1986 and 1991 censuses were only available at the CAU level. However, CAUs are still capable of capturing differences within communities and cities, making them a suitable alternative to meshblocks. The median number of individuals aged 15 years old and over within a CAU was 1161.0 in 1981, 1314.0 in 1986, and 1308.0 in 1991. The median number of private dwellings within a CAU was 501.0 in 1981, 589.5 in 1986, and 591.0 in 1991. Detailed distribution data for counts of individuals aged 15 years and over and private dwellings within CAUs for these three years can be found in the supplementary notes (Figure S7).

Stats NZ has rebased some of the old census data to the latest version of its geographic boundaries. Specifically, the data from the 1981 Census are now based on the 2001 (sic) CAU boundary, the data from the 1986 Census are based on the 1996 (sic) CAU boundary, and the data from the 1991Census are based on the 2006 (sic) CAU boundary.

In this study, CAUs that are oceanic, water inlets, lakes or harbour ports were excluded from analysis ($n = 97$ for 1981, $n = 81$ for 1986, and $n = 109$ for 1991). Due to the lack of information about land classification at the CAU level, this process had to be done manually. To identify these CAUs, keywords such as ‘inlet’, ‘inland water’, ‘harbour’, and ‘oceanic’ in the names of the CAUs were selected and manually checked against satellite images to confirm their location in water areas. CAUs that included mostly land but had a small portion of water were still included in the analysis. Table 1 shows the number of CAUs that were excluded. Approximately 5 per cent of CAUs in all three censuses were in water areas and were excluded from the analysis. After cleaning, the census data were linked to the corresponding geographic boundaries using CAU identifiers.

Table 1: The number of excluded CAUs from the 1981, 1986 and 1991 census data

Census year	Boundaries year	Original polygons (*n*)	Excluded (*n*)	After cleaning (*n*, %)
1981	2001	1842	98	1744, 94.7%
1986	1996	1767	82	1685, 95.4%
1991	2006	1909	110	1799, 94.2%

Converting data between geographic boundaries

Geographic boundaries changed between the census years 1981, 1986 and 1991. These changes were made to ensure that the statistical geographic boundaries accurately represent the current population and housing growth. However, to create a comparable area-level deprivation metric over time, it is essential to ensure that the census data from 1981, 1986 and 1991 are aligned to the same geographic boundaries (Norman, 2010; Norman et al., 2003). Failure to do so may result in ambiguity, making it challenging to discern whether changes in the deprivation metric are due to actual changes in the socioeconomic conditions or simply due to alterations in the geographic boundaries (Norman, 2010).

To establish a time-series area-level deprivation metric, data from the 1981 Census (2001 geographic boundaries) and 1986 Census (1996 geographic boundaries) were converted to the geographic boundaries of the data from the 1991 Census (2006 geographic boundaries). Norman (2010) and Norman et al. (2008) describe a method of converting census data between different geographic boundaries. The method involves constructing intersection zones between the source geography and the target geography by overlaying the two geographic boundaries, as illustrated in Figure 3. The raw census data in the source geography could then be apportioned to the intersection zones using population weights based on the population where

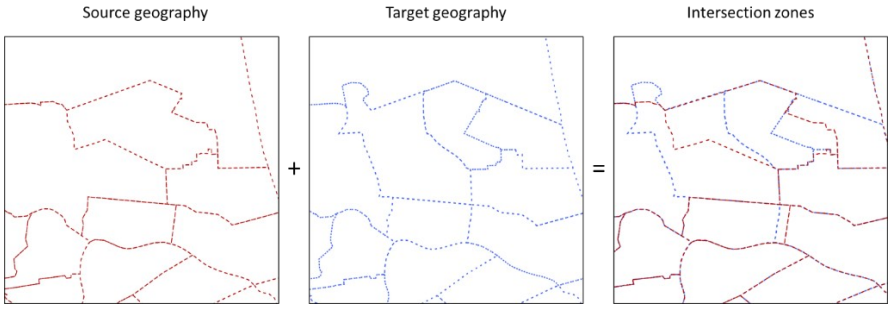
the intersection zones and the source geographic boundaries overlap. Finally, the data in the intersection zones can be aggregated to the target geography. The highlight of this approach is that it recognises that population distribution is uneven across space and uses population weights to account for this variability (Norman, 2010).

Building upon Norman's approach, this study applied the following steps to convert the data from the 1981 and 1986 censuses to the geographic boundaries for the 1991 Census:

1. Identify the intersection zones between the 1981 and 1991 geographic boundaries and between the 1986 and 1991 geographic boundaries.
2. Calculate the population in the intersection zones and their source geographies.
3. Construct the conversion table by dividing the population in the intersection zones by the population in their source geographic boundary.
4. Apportion raw census data from the source geography to the intersection zones.
5. Aggregate the census data across the target geographic boundary.

This study utilised residential buildings around 1985 as a proxy of population distribution in 1981, 1986 and 1991. This decision was based on two assumptions: 1) that an equal number of people lived in each building, and 2) that the distribution of residential buildings in 1985 was the same as that in 1981, 1986 and 1991. While we acknowledge the variability in building numbers over time, we maintain that this assumption is grounded in a reasonable estimation given the relatively stable population trends during the specified period (Statistics New Zealand, 2014). The methods of developing the proxy measure for population distribution around 1985 can be found in the supplementary notes.

Figure 3: Constructing intersection zones between a source geography and a target geography



Calculating and constructing the area-level deprivation metric

After converting data to the same geography basis, the percentages of unemployment and non-home ownership were calculated using Equation (1) and Equation (2), respectively.

$$\text{Unemployment (\%)} = \frac{\text{Unemployed people} * 100}{\text{People who are 15 years and over} - \text{People who are 15 years and over but not in labour force}} \quad (1)$$

$$\text{Non-home ownership (\%)} = \frac{\text{Private dwellings that are rented} * 100}{\text{All private dwellings} - \text{provided free} - \text{not specified}} \quad (2)$$

Due to the skewed distribution of the resulting percentages of unemployment and non-home ownership, they were normalised using a median absolute deviation (MAD) transformation, described in Equation (3) and Equation (4). The normalisation process involved stacking the data from the three censuses into a single file, allowing each variable to be expressed relative to the three-year coverage. Area-level deprivation scores were calculated by adding up the two normalised percentages with equal weights. To enhance the

convenience of usage and visualisation, the area-level deprivation scores were further divided into population-weighted quintiles.

(3)

where:

X_i denotes a single data value

denotes the median of the data set, and

mad(X) is determined from Equation (4).

And:

(4)

where:

median(X) is the median value of the data set.

Validation for the area-level deprivation metric

To validate and justify the appropriateness of utilising unemployment and non-home ownership as indicators for area-level deprivation, an analysis was conducted using the Townsend Deprivation Index for the UK in 2001 and 2002. From this index, a separate metric was generated by combining standardised unemployment and non-home ownership percentages, assigning equal weights to each variable. Subsequently, the correlation between this generated metric, which solely considers these two variables and the original Townsend deprivation score, was calculated for both years.

To further investigate the suitability of utilising unemployment and non-home ownership as indicators of area-level deprivation in New Zealand, a second correlation test was performed between the deprivation score derived from this study and the NZDep 1991 deprivation score at the CAU level. It is worth noting that in this analysis, we used the original deprivation scores from the 1991 NZDep rather than the deciles that are more commonly used in various applications. However, there was a discrepancy in the boundaries used: the deprivation metric derived in this study in 1991 was based on the 2006 CAU

boundary, while the NZDep 1991 deprivation score was based on the 1991 CAU boundary. To address this issue, the 2006 CAU boundaries were converted into centroids, and their corresponding deprivation scores were retained. These centroids were then joined to the 1991 CAU boundaries by their spatial relationship. In cases where multiple centroids from the 2006 CAU fell within one 1991 CAU, various statistical measures such as the minimum, maximum, mean and median values of the deprivation scores were calculated. Subsequently, the correlation test was conducted using these statistical measures (minimum, maximum, mean and median values) of the deprivation scores derived in this study and the NZDep 1991 deprivation scores. A correlation test was conducted for the CAUs where deprivation scores exist in both metrics ($n = 1596$).

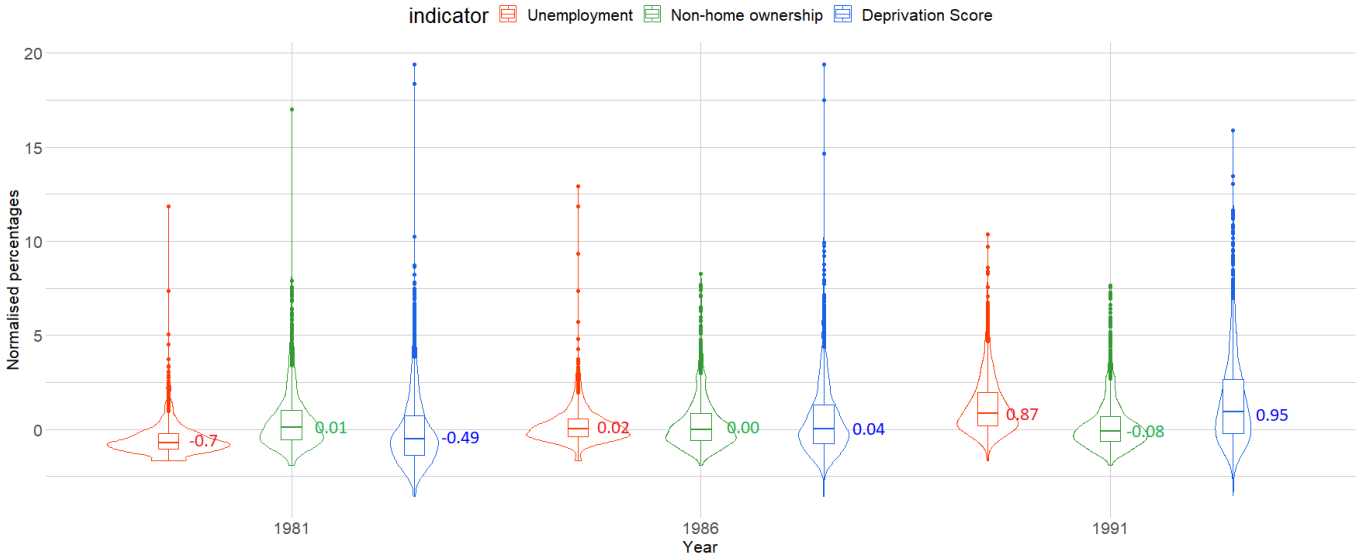
A Pearson's product-moment correlation coefficient was employed to quantify the strength of the correlations for both tests.

Results

National-level analysis of the area-level deprivation metric

Figure 4 depicts the distribution of the normalised values for the two variables – unemployment and non-home ownership percentages – along with area-level deprivation scores in 1981, 1986 and 1991. The unemployment percentages demonstrate a significant increase from 1981 to 1991, while the non-home ownership percentages remained relatively stable across the three census years. The deprivation score showed an increase in deprivation from 1981 to 1991, as evidenced by the median deprivation score rising from −0.49 in 1981 to 0.95 in 1991. The variance in area-level deprivation scores was smaller in 1991 than in 1981 and 1986, but the values around the median score exhibited greater variation.

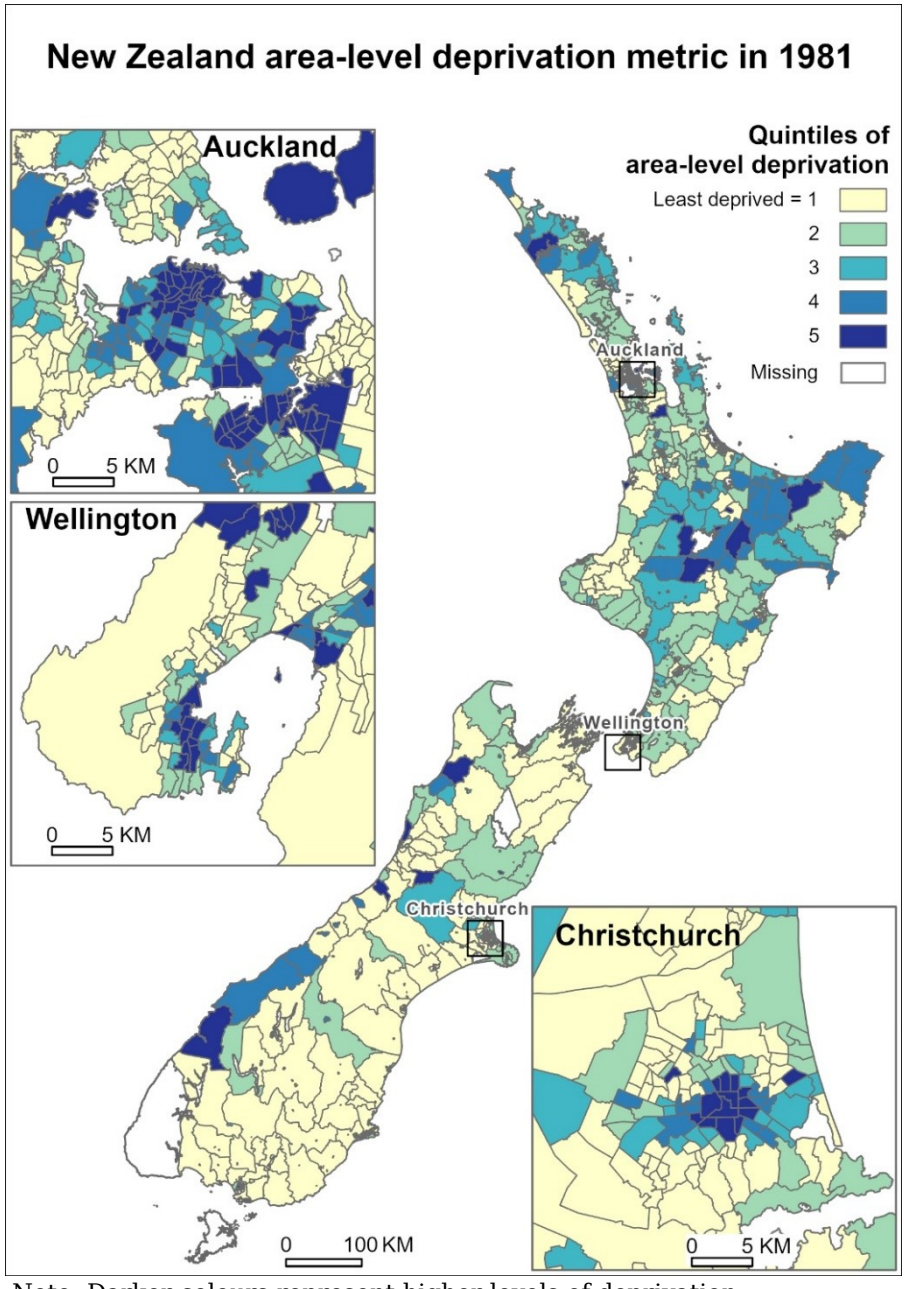
Figure 4: The distribution of normalised unemployment, non-home ownership percentages, and the area-level deprivation scores in 1981, 1986 and 1991



Figures 5a–5c visualise the time-series area-level deprivation across the 1981, 1986 and 1991 census years. In 1981, the most deprived areas (darker colours) were concentrated in the far north, central and eastern areas of the North Island, as well as in some areas of the West Coast of the South Island. The city centres of Auckland, Wellington and Christchurch exhibited higher levels of deprivation compared with their fringe areas. Notably, the southeastern Auckland region displayed a high area-level deprivation status. By 1986, the far north, central and eastern areas of the North Island and some areas on the West Coast of the South Island remained the most deprived areas, with the North Island appearing more deprived overall than the South Island. In addition, the area-level deprivation level was low in the southernmost part of the South Island. In metropolitan areas, the most deprived areas still clustered in the city centres, while more areas on the fringes showed an increase in area-level deprivation. Moving to 1991, the national area-level deprivation patterns remained largely similar to those observed in 1986. However, a notable increase was observed in some CAUs in Auckland, Wellington and Christchurch, experiencing higher levels of deprivation compared to 1986. Maps of the area-level deprivation metric for other cities in New Zealand are provided in the supplementary notes (Figures S10–S14).

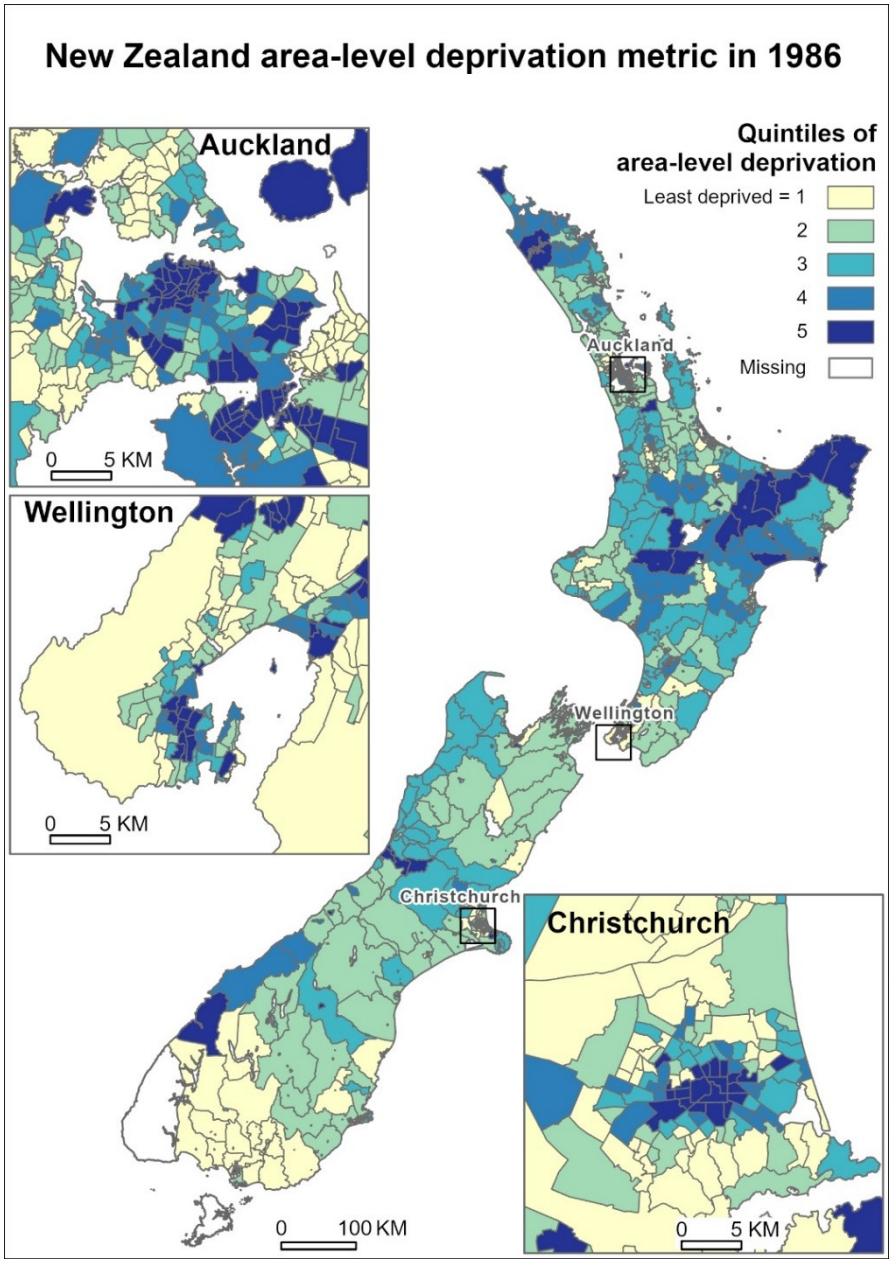
Upon reviewing Figures 5a–5c and Figures S10–S14, two general patterns emerge: 1) the city centres exhibit higher levels of deprivation compared with their fringe areas, and 2) these characteristics remained consistent over the decade from 1981 to 1991.

Figure 5a: Visualisation of the area-level deprivation metric in 1981



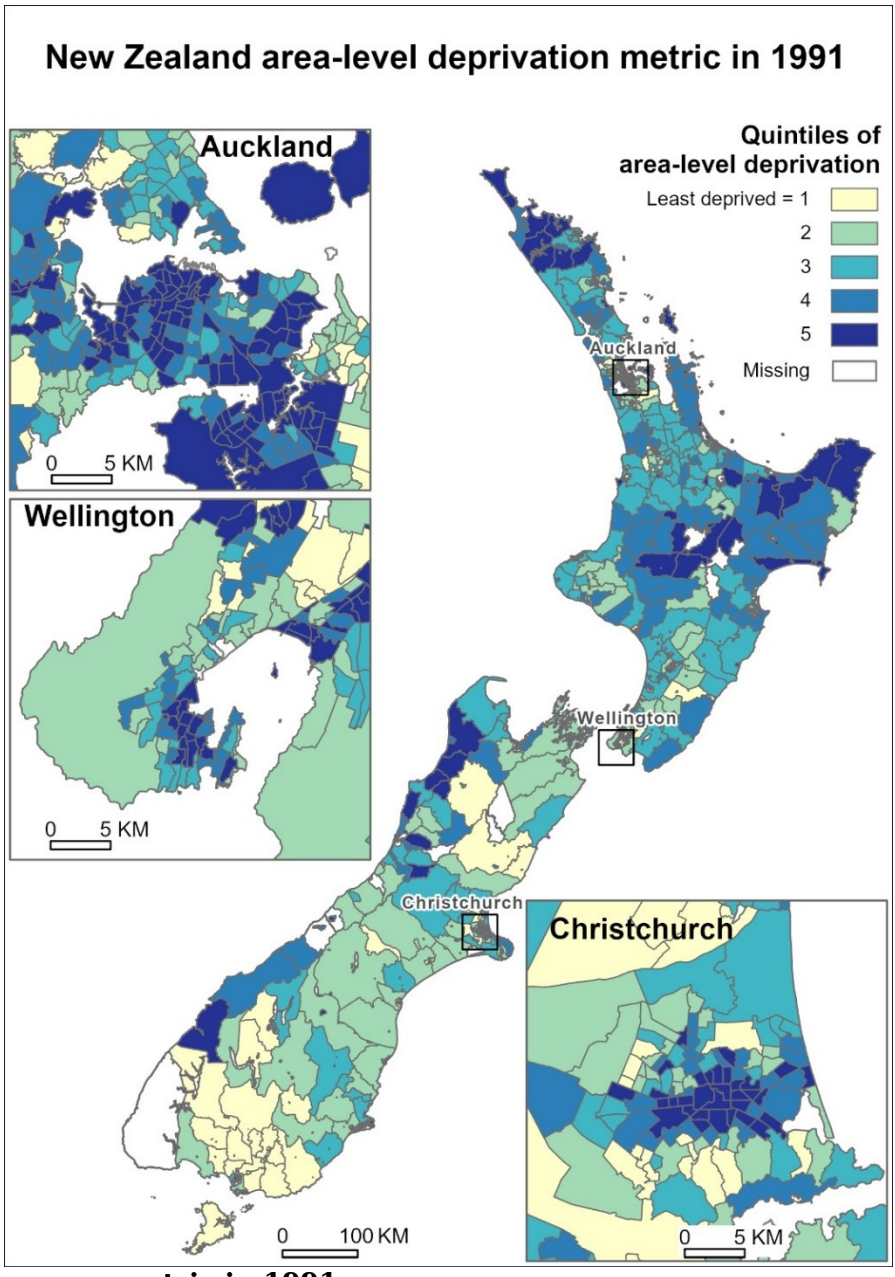
Note: Darker colours represent higher levels of deprivation.

Figure 5b: Visualisation of the area-level deprivation metric in 1986



Note: Darker colours represent higher levels of deprivation.

Figure 5c: Visualisation of the area-level deprivation metric in 1991



Note: Darker colours represent higher levels of deprivation.

Table 2 compares the counts of CAUs that changed in area-level deprivation in each pair of the two time periods. From 1981 to 1986, 52.9 per cent of the areas remained unchanged in terms of area-level deprivation, 42.0 per cent of the areas in 1986 exhibited increased deprivation compared with 1981, and only 5.0 per cent of the areas in 1986 had lower deprivation levels than in 1981. From 1986 to 1991, 41.0 per cent of the areas remained unchanged in terms of area-level deprivation, 53.1 per cent of the areas in 1991 exhibited increased deprivation compared with 1986, and only 5.9 per cent of the areas in 1991 had lower deprivation levels than in 1986. During the decade from 1981 to 1991, 69.9 per cent of areas in 1991 exhibited increased deprivation compared with 1981, only 27.2 per cent of areas had no changes in their deprivation scores, and only 2.9 per cent of the areas (50 CAUs) in 1991 had lower deprivation levels than in 1981. Visualisations of these changes at a national level, as well as in Auckland, Wellington and Christchurch (Figures S15a–c), and other cities (Figures S16–S20), are available in the supplementary notes.

Table 2: Counts of unchanged, more-deprived and less-deprived areas in the area-level deprivation metric

	Unchanged	More deprived	Less deprived
1981 to 1986	936 (52.9%)	743 (42.0%)	89 (5.0%)
1986 to 1991	714 (41.0%)	924 (53.1%)	102 (5.9%)
1981 to 1991	474 (27.2%)	1216 (69.9%)	50 (2.9%)

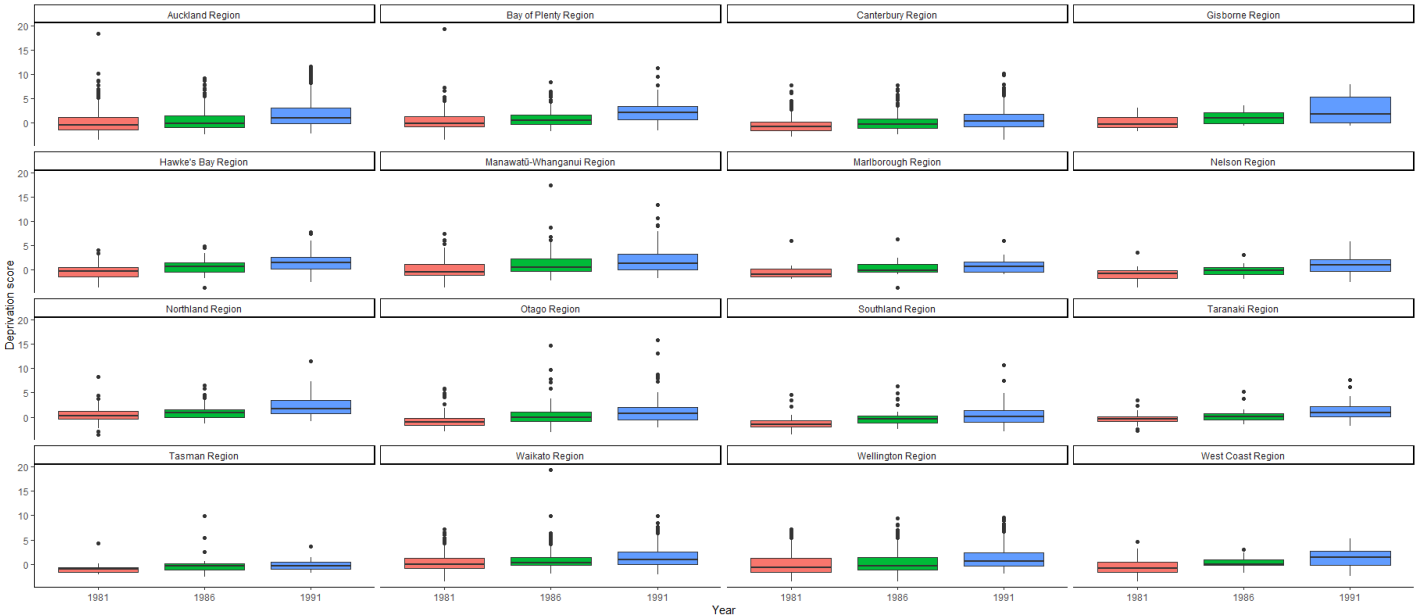
Regional-level analysis of the area-level deprivation metric

Figure 6 presents the distribution of deprivation quintiles over time by administrative regions. The results demonstrate a consistent pattern of increasing area-level deprivation from 1981 to 1991 across all administrative regions. Specifically, the level of deprivation in 1986 was higher than that in 1981, and the level of deprivation in 1991 was higher than that in 1986. This gradient in area-level deprivation was observed in all regions. Some regions, including Auckland, Hawke's Bay, Whanganui, Northland, Southland and the West Coast, have witnessed a larger variance in terms of deprivation levels in 1991, aligning with the national trend.

The proportions of CAUs that experienced changes of varying extent in area-level deprivation quintiles within each administrative region are presented in the supplementary notes for the periods from 1981 to 1986 (Figure S21), from 1986 to 1991 (Figure S22), and from 1981 to 1991 (Figure S23). From 1981 to 1986, Auckland and Marlborough stand out as the regions with the smallest and the largest proportions of CAUs, respectively, that became more deprived over this five-year period. On the other hand, Northland is the region that exhibited the largest proportion of CAUs experiencing an improvement in area-level deprivation. From 1986 to 1991, the Marlborough and Nelson regions had exhibited the smallest and largest proportions of CAUs, respectively, that experienced increased deprivation over this five-year period. However, it is worth noting that all regions observed improvements in area-level deprivation in certain CAUs. Overall, from 1981 to 1991, over the decade, a substantial percentage of CAUs experienced an increase in deprivation, ranging from approximately 50 per cent in Tasman to more than 80 per cent in Gisborne. On the other hand, Nelson had the largest percentage of CAUs that became less deprived, accounting for about 8 per cent. Notably, five regions – Southland, Bay of Plenty, Taranaki, Hawke's Bay and Gisborne – did not have any CAUs that experienced a decrease in

deprivation, indicating consistent or worsening deprivation levels across all CAUs within these regions in this decade.

Figure 6: The distribution of area-level deprivation scores by administrative regions and over time, 1981 to 1991



Validation for the area-level deprivation metric

The correlation coefficient between the area-level deprivation metric, obtained by summing only two variables (unemployment and non-home ownership) from the UK-based Townsend Deprivation Index, and the original Townsend deprivation score was found to be 0.96 in 2001 and 0.95 in 2011 ($p < 0.0001$). This suggests that the variables of unemployment and non-home ownership are sufficient to explain most of the variance in the UK-based Townsend Deprivation Index.

A second correlation test, which also used Pearson's product-moment corelation coefficient to quantify corelation, was performed between the area-level deprivation scores in 1991 derived from this study and the NZDep 1991 deprivation scores derived from Crampton et al. (1997). The analysis revealed positive correlations, with correlation coefficients ranging from 0.804 (using the minimum deprivation score) to 0.814 (using the mean deprivation score) ($p < 0.001$). These results demonstrate that the deprivation metric in 1991 constructed in this study is correlated with NZDep 1991, thereby suggesting again that our measure is a possible proxy for average CAU-level deprivation in New Zealand.

Discussion

This study aimed to construct a consistent time-series area-level deprivation metric in 1981, 1986 and 1991 in New Zealand at the CAU level. Findings from our study revealed a consistent increase in area-level deprivation across the country during the studied decade, surpassing the available data from 1991. Certain areas, namely the far north, central and eastern areas of the North Island, along with the west coast of the South Island, consistently remained the most deprived areas throughout the period. All administrative regions experienced an increase in area-level deprivation over the decade from 1981 to 1991 but with varying magnitudes of change. Furthermore, most metropolitan areas consistently exhibited higher levels of deprivation in their city centres compared with their fringe areas. Importantly, we demonstrated that the choice of indicators in our area-level deprivation metric is reasonable, and our measure of

area-level deprivation was correlated with the NZDep 1991 area-level deprivation scores.

This study demonstrates an increase in area-level deprivation in New Zealand between 1981 and 1991. This period coincided with extensive neoliberal social and economic reforms implemented in New Zealand, starting in the mid-1980s (Baxendine et al., 2005; Dalziel, 2002; Denemark, 1999; Pearce & Dorling, 2006). These reforms involved various measures, such as the freeing of interest rates from regulations, elimination of restrictions on international capital, allowing the currency to float in foreign exchange markets, and gradually reducing agricultural subsidies and tax incentives (Dalziel, 2002). Some people considered these reform measures were generally successful as they transformed the economy from one of the most interventionist among the Organisation for Economic Co-operation and Development (OECD) countries to one of the most market-based (Conway & Orr, 2000). However, critics argued that these policies were accompanied by a significant increase in unemployment (Baxendine et al., 2005; Dalziel, 2002; Denemark, 1999). Specifically, during the 1986 to 1991 period, the nation experienced a decline of 9.7 per cent in total full-time employment and 7.6 per cent in total headcount employment (Baxendine et al., 2005). Our study aligns with these concerns, as it observed a similar pattern of increased unemployment rates during the 1986 to 1991 period which were not evenly distributed across the country. Furthermore, consistent with our study's finding that area-level deprivation increased across all administrative regions from 1981 to 1991, Baxendine et al. (2005) conducted a spatial analysis of labour markets from 1986 to 2001 and also observed that all administrative regions experienced a decline in full-time employment during the 1986–1991 period in New Zealand. It is worth noting that while the reforms also involved housing policies, those changes related to housing policies were implemented after the census night in March 1991 (Campbell, 1999). This may explain why no dramatic changes in home ownership percentages were observed within the time frame studied.

It is important to acknowledge that while our metric shows a consistently higher level of deprivation in city centres compared with their fringe areas over time, this disparity may not necessarily reflect

genuine deprivation. We cannot ignore the fact that non-homeownership constitutes a half of the metric. In city centres, there might be a concentration of more transient populations (e.g., university students) (Marek et al., 2023) who often prefer renting over homeownership due to the flexibility renting affords, and their presence in the city centre may skew the measurement of deprivation in these areas.

Having access to this historical time-series area-level deprivation metric opens up new possibilities for future studies in New Zealand to gain a better understanding of how significant socioeconomic transformations impact individual health and how neighbourhood deprivation affects health outcomes over time. A study in the UK sheds light on this matter, indicating that individuals residing in economically disadvantaged neighbourhoods at the onset of the 2008 “great recession” experienced a significantly higher risk of declining mental health (Curtis et al., 2021). Furthermore, Boyle et al. (2023) conducted a study that modelled historical neighbourhood deprivation, providing evidence of historical neighbourhood deprivation as a risk factor for non-Hodgkin’s lymphoma. Additionally, area-level deprivation may interact with individual-level socioeconomic disadvantage to influence health outcomes (Baranyi et al., 2022; Baumer et al., 2023; Hong et al., 2023).

These new data within our area-level deprivation metric from 1981 to 1991 have important implications. First, the data offer valuable insights into the socioeconomic disadvantages and inequalities at the CAU level since 1981. The data, therefore, enables the identification of small areas that have been persistently deprived since 1981, such as the far north. This information is helpful for understanding and addressing long-standing socioeconomic disparities within New Zealand (Hobbs et al., 2019). The information is also useful when allocating resources to areas that have been historically disadvantaged or marginalised (Exeter et al., 2017; Salmond & Crampton, 2012). Additionally, the availability of this historical area-level deprivation metric enables the evaluation of past policies (e.g., the social and economic reforms in 1984) (Conway & Orr, 2000; Dalziel, 2002) and interventions aimed at addressing area-

level deprivation-related issues and minimising socioeconomic inequalities.

This study has several key strengths that make significant contributions to the field of area-level deprivation research in New Zealand. First, the metric developed in this study makes it possible to examine area-level deprivation before 1991, allowing for an analysis of the evolution of area-level deprivation from as early as 1981. Before the development of this metric, there was no way to examine area-level deprivation consistently before 1991 in New Zealand. Secondly, the study uses consistent variables, statistical methods and geographic units to construct the area-level deprivation metric, making it possible to compare deprivation data over time (Salmond & Crampton, 2012). This is particularly important for longitudinal studies, as it allows for analysis of changes in deprivation over time (Norman, 2010; Norman et al., 2003; Salmond & Crampton, 2012). Thirdly, while census-based area-level deprivation metrics possess inherent limitations concerning timeliness (Exeter et al., 2017; Ward et al., 2019) and the use of proxy measures of area-level deprivation (Exeter et al., 2017; Norman, 2010), metrics utilising census data provide superior comparability across countries and over time (Allik et al., 2016). This is because census questions remain relatively constant across different countries and over time, making them popular in larger comparative studies (Allik et al., 2016; Exeter et al., 2011; Marí-Dell'Olmo et al., 2015; Norman et al., 2011).

While this study represents a significant advancement in understanding historically relevant area-level deprivation, it is important to acknowledge its limitations. First, the selection of indicators in constructing this area-level deprivation metric was constrained by data availability rather than being driven solely by the phenomenon of interest. While it has been validated that the variables of unemployment and non-home ownership can capture much of the data required for this study, it is important to note that this metric may only capture limited aspects of area-level deprivation. Socioeconomic deprivation is a multi-faceted construct that is hard to measure, hence the common use of composite measures that have several variables. It would be expected that this index, being reliant on only two variables neither of which are income or education, would not reproduce the consistently strong

relationships that are normally seen across a wide range of health and social outcomes. Attempts were made to incorporate variables into this metric including non-car ownership and overcrowding, but due to issues such as many missing values and low response rates, ultimately these variables were not utilised in the metric. Likewise, other variables such as education attainment and household income, which are commonly incorporated into deprivation measures, were not included due to historical data availability. Secondly, while significant efforts were made to process the data into a cohesive structure, some uncertainties in the data remain. Thirdly, the nature of census data may introduce potential biases in terms of varying response rates across different areas. Potentially, more-deprived areas produce lower response rates, which could result in an underestimation of unemployment or non-home ownership rates (Goodman & Gatward, 2008; Turrell et al., 2003). Fourthly, the census data were converted between different geographic boundaries based on residential buildings in 1985 as a proxy of population distribution; relying solely on this proxy may produce inaccurate results as this measure can only provide an approximate representation of population distribution. Also, this metric focuses on the changes between 1981 and 1991, but the method of constructing this metric is not easy to be generalised to produce a similar one for recent years due to the complexity of the geographical conversion methods. Lastly, it is important to acknowledge that the Modifiable Areal Unit Problem (MAUP) is inherent to this study. The selection of geographic boundaries was constrained by data availability, and using alternative boundaries such as suburbs or administrative areas may yield different results (Cebrecos et al., 2018). The employment of CAUs as the geographic unit in this metric can potentially mask many pockets of deprivation because CAUs are on a larger scale than the finer meshblock or data zone units employed by other commonly used deprivation indices in New Zealand. However, the prospect for further improvement exists if historical census data can be restored and made accessible at the meshblock level in the near future. This would enable the use of customised geographic units, thus mitigating the risk of the MAUP.

Conclusion

The historically relevant time-series area-level deprivation metric extends the understanding of area-level deprivation across the 1980s, as previous data on area-level deprivation in New Zealand were only available starting from 1991. The resulting metric not only contributes to the understanding of spatial area-level deprivation dynamics in New Zealand since 1981 but also offers valuable data for investigating the long-term impacts of area-level deprivation on various societal and public health outcomes. This metric holds importance by providing insights into persistent area-level deprivation over time, which may help with directing resources towards underserved and marginalised areas, evaluating past policies, and informing future planning.

Notes

1 Link to the supplementary notes (including figures) needs to go in here.

Acknowledgements

This project was funded by a New Zealand Health Research Council Emerging Researcher First Grant (22/528).

Thanks to Ben Magson for his invaluable assistance with data wrangling and preliminary data analysis during the early stages of this project.

References

Adams, R. J., Howard, N., Tucker, G., Appleton, S., Taylor, A. W., Chittleborough, C., Gill, T., Ruffin, R. E., & Wilson, D. H. (2009). Effects of area deprivation on health risks and outcomes: A multilevel, cross-sectional, Australian population study. *International Journal of Public Health*, *54*, 183–192. https://doi.org/10.1007/s00038-009-7113-x

Allik, M., Brown, D., Dundas, R., & Leyland, A. H. (2016). Developing a new small-area measure of deprivation using 2001 and 2011 census data from Scotland. *Health & Place*, *39*, 122–130. https://doi.org/10.1016/j.healthplace.2016.03.006

Allik, M., Leyland, A., Ichihara, M. Y. T., & Dundas, R. (2020). Creating small-area deprivation indices: a guide for stages and options.

Journal of Epidemiology and Community Health, *74*(1), 20–25. http://dx.doi.org/10.1136/jech-2019-213255

Atkinson, J., Salmond, C., & Crampton, P. (2014). *NZDep2013 index of deprivation*. https://www.otago.ac.nz/wellington/otago069936.pdf

———— (2019). *NZDep2018 Index of Deprivation*. https://www.otago.ac.nz/wellington/otago730394.pdf

Australian Bureau of Statistics. (2013). *Socio-Economic Indexes for Areas* (SEIFA) (Technical paper). https://www.abs.gov.au/statistics/detailed-methodology-information/concepts-sources-methods/socio-economic-indexes-areas-seifa-technical-paper/2021

Baranyi, G., Welstead, M., Corley, J., Deary, I. J., Muniz-Terrera, G., Redmond, P., Shortt, N., Taylor, A. M., Ward Thompson, C., & Cox, S. R. (2022). Association of Life-Course Neighborhood Deprivation with Frailty and Frailty Progression from Ages 70 to 82 Years in the Lothian Birth Cohort 1936. *American Journal of Epidemiology*, *191*(11), 1856–1866. http://dx.doi.org/10.1093/aje/kwac134

Barbek, R. M., Makowski, A. C., & von dem Knesebeck, O. (2022). Social inequalities in health anxiety: A systematic review and meta-analysis. *Journal of Psychosomatic Research*, *153*, Article 110706. https://doi.org/10.1016/j.jpsychores.2021.110706

Baumer, Y., Pita, M. A., Turner, B. S., Baez, A. S., Ortiz-Whittingham, L. R., Gutierrez-Huerta, C. A., Neally, S. J., Farmer, N., Mitchell, V. M., & Collins, B. S., & Powell-Wiley, T. M. (2023). Neighborhood socioeconomic deprivation and individual-level socioeconomic status are associated with dopamine-mediated changes to monocyte subset CCR2 expression via a cAMP-dependent pathway. *Brain, Behavior, & Immunity-Health*, *30*, Article 100640. http://dx.doi.org/10.1016/j.bbih.2023.100640

Baxendine, S., Cochrane, W., & Poot, J. (2005). *Description and spatial analysis of employment change in New Zealand regions 1986–2001* (Discussion paper No. 57). Population Studies Centre, University of Waikato. https://researchcommons.waikato.ac.nz/server/api/core/bitstreams/405a8702-6e4d-49e7-82a9-42d3c181428c/content

Boyle, J., Ward, M. H., Cerhan, J. R., Rothman, N., & Wheeler, D. C. (2023). Modeling historic neighborhood deprivation and non-Hodgkin lymphoma risk. *Environmental Research*, *232*, Article 116361. https://doi.org/10.1016/j.envres.2023.116361

Cairns, J.-M., Graham, E., & Bambra, C. (2017). Area-level socioeconomic disadvantage and suicidal behaviour in Europe: A systematic review. *Social Science & Medicine*, *192*, 102–111. https://doi.org/10.1016/j.socscimed.2017.09.034

Campbell, S. (1999). *Restructuring New Zealand housing policy, 1990–1998: An institutional analysis* [Master's thesis, University of Canterbury]. UC Research Repository. https://ir.canterbury.ac.nz/handle/10092/8628

Carstairs, V., & Morris, R. (1989). Deprivation: Explaining differences in mortality between Scotland and England and Wales. *British Medical Journal*, *299*(6704), 886–889. https://doi.org/10.1136%2Fbmj.299.6704.886

———— (1990). Deprivation and health in Scotland. *Health Bull (Edinburgh)*, *48*(4), 162–175. PMID: 2394583. https://pubmed.ncbi.nlm.nih.gov/2394583/

Cebrecos, A., Domínguez-Berjón, M. F., Duque, I., Franco, M., & Escobar, F. (2018). Geographic and statistic stability of deprivation aggregated measures at different spatial units in health research. *Applied Geography*, *95*, 9–18. https://doi.org/10.1016/j.apgeog.2018.04.001

Conway, P., & Orr, A. (2000). The process of economic growth in New Zealand. *Reserve Bank of New Zealand Bulletin*, *63*(1), 4–20. https://www.rbnz.govt.nz/-/media/df21863aa4e642f7b03da42af8e858fa.ashx?sc_lang=en

Crampton, P. R., Sutton, F., & Salmond, C. E. (1998). *NZDep91: Index of deprivation*. Australia and new Journal of Public Health, 22(7), 835–7. PMID 9889455. https://doi.org/10.1111/j.1467-842x.1998.tb01505.x

Curtis, S., Cunningham, N., Pearce, J., Congdon, P., Cherrie, M., & Atkinson, S. (2021). Trajectories in mental health and socio-spatial conditions in a time of economic recovery and austerity: A longitudinal study in England 2011–17. *Social Science & Medicine*, *270*, Article 113654. https://doi.org/10.1016/j.socscimed.2020.113654

Dalziel, P. (2002). New Zealand's economic reforms: An assessment. *Review of Political Economy*, *14*(1), 31–46. https://doi.org/10.1080/09538250120102750

Denemark, D. (1999). Social democracy and contextual unemployment: New Zealand labour in 1990. *Australian Geographer*, *30*(2), 197–220.

Department of Statistics New Zealand. (1992). *New Zealand Standard Areas Classification Manual 1992*. Department of Statistics New Zealand. https://statsnz.contentdm.oclc.org/digital/collection/p20045coll1/id/2686/

Diaz, A., O'Reggio, R., Norman, M., Thumma, J. R., Dimick, J. B., & Ibrahim, A. M. (2021). Association of historic housing policy, modern day neighborhood deprivation and outcomes after inpatient hospitalization. *Annals of Surgery*, *274*(6), 985–991. https://doi.org/10.1097/sla.0000000000005195

Ejlskov, L., Antonsen, S., Wulff, J. N., Agerbo, E., Plana-Ripoll, O., Sabel, C. E., Fan, C. C., Thompson, W. K., Mok, P. L., & Pedersen, C. B. (2023). Multilevel interactions between family and neighbourhood socioeconomic indices in childhood and later risks of self-harm and violent criminality in Denmark: A national cohort study. *The Lancet Public Health*, *8*(2), e99–e108. https://doi.org/10.1016/S2468-2667(22)00292-4

Exeter, D., Browne, M., Annie, C., Crengle, S., Zhao, J., & Lee, A. (2018). *The 2018 New Zealand Index of Multiple Deprivation (IMD18): Indicators for social and health research in New Zealand – Brief report–*. School of Population Health, University of Auckland. https://bpb-ap-se2.wpmucdn.com/blogs.auckland.ac.nz/dist/3/843/files/2021/09/Brief-report-IMD18.pdf

Exeter, D. J., Boyle, P. J., & Norman, P. (2011). Deprivation (im)mobility and cause-specific premature mortality in Scotland. *Social Science & Medicine*, *72*(3), 389–397. https://doi.org/10.1016/j.socscimed.2010.10.009

Exeter, D. J., Feng, Z., Zhao, J., Cavadino, A., & Norman, P. (2019). The geographic harmonisation of Scotland's small area census data, 1981 to 2011. *Health & Place*, *57*, 22–26. https://doi.org/10.1016/j.healthplace.2019.02.003

Exeter, D. J., Zhao, J., Crengle, S., Lee, A., & Browne, M. (2017). The New Zealand Indices of Multiple Deprivation (IMD): A new suite of indicators for social and health research in Aotearoa, New Zealand. *PLoS one*, *12*(8), Article e0181260. https://doi/org/10.1371/journal.pone.0181260

Fu, M., Exeter, D. J., & Anderson, A. (2015). The politics of relative deprivation: A transdisciplinary social justice perspective. *Social Science & Medicine*, *133*, 223–232. https://doi.org/10.1016/j.socscimed.2014.12.024

Goodman, A., & Gatward, R. (2008). Who are we missing? Area deprivation and survey participation. *European Journal of Epidemiology*, *23*, 379–387. https://doi.org/10.1007/s10654-008-9248-0

Hobbs, M., Ahuriri-Driscoll, A., Marek, L., Campbell, M., Tomintz, M., & Kingham, S. (2019). Reducing health inequity for Māori people in New Zealand. *Lancet*, *394*(10209), 1613–1614. https://doi.org/10.1016/s0140-6736(19)30044-3

Hong, Y. D., Mullins, C. D., Onukwugha, E., Yared, J. A., Zheng, Z., & Slejko, J. F. (2023). Association of individual low-income status and area deprivation with mortality in multiple myeloma. *Journal of Geriatric Oncology*, *14*(2), Article 101415. https://doi.org/10.1016/j.jgo.2022.12.003

Jarman, B. (1991). Jarman index. *British Medical Journal, 302*(6782), 961–962. https://doi.org/10.1136/bmj.302.6782.961-c

Jivraj, S., Murray, E. T., Norman, P., & Nicholas, O. (2020). The impact of life course exposures to neighbourhood deprivation on health and well-being:
A review of the long-term neighbourhood effects literature. *European Journal of Public Health*, *30*(5), 922–928. https://doi.org/10.1093/eurpub/ckz153

Kind, A. J., & Buckingham, W. R. (2018). Making neighborhood-disadvantage metrics accessible—the neighborhood atlas. *The New England Journal of Medicine*, *378*(26), Article 2456. https://doi.org/10.1056%2FNEJMp1802313

Marek, L., Hills, S., Wiki, J., Campbell, M., & Hobbs, M. (2023). Towards a better understanding of residential mobility and the environments in which adults reside: A nationwide geospatial study from Aotearoa New Zealand. *Habitat International*, *133*, Article 102762. https://doi.org/10.1016/j.habitatint.2023.102762

Marí-Dell'Olmo, M., Gotsens, M., Palència, L., Burström, B., Corman, D., Costa, G., Deboosere, P., Díez, È., Domínguez-Berjón, F., & Dzúrová, D. (2015). Socioeconomic inequalities in cause-specific mortality in 15 European cities. *Journal of Epidemiology and Community Health*, *69*(5), 432–441. https://doi.org/10.1136/jech-2014-204312

Murakami, K., Sasaki, S., Okubo, H., Takahashi, Y., & Freshmen in Dietetic Courses Study II Group. (2009). Neighborhood socioeconomic status in relation to dietary intake and body mass index in female Japanese dietetic students. *Nutrition*, *25*(7–8), 745–752. https://doi.org/10.1016/j.nut.2009.01.010

Norman, P. (2010). Identifying change over time in small area socio-economic deprivation. *Applied Spatial Analysis and Policy*, *3*, 107–138. http://dx.doi.org/10.1007/s12061-009-9036-6

———— (2016). The changing geography of deprivation in Britain: 1971 to 2011 and beyond. In T. Champion & J. Falkingham (Eds.), *Population Change in the United Kingdom* (pp. 193–214). Rowman & Littlefield International.

Norman, P., Boyle, P., Exeter, D., Feng, Z., & Popham, F. (2011). Rising premature mortality in the UK's persistently deprived areas: Only a Scottish phenomenon? *Social Science & Medicine*, *73*(11), 1575–1584. https://doi.org/10.1016/j.socscimed.2011.09.034

Norman, P., Rees, P., & Boyle, P. (2003). Achieving data compatibility over space and time: Creating consistent geographical zones. *International Journal of Population Geography*, *9*(5), 365–386. https://doi.org/10.1002/ijpg.294

Norman, P., Simpson, L., & Sabater, A. (2008). 'Estimating with Confidence'and hindsight: New UK small-area population estimates for 1991. *Population, Space and Place*, *14*(5), 449–472. https://doi.org/10.1002/psp.492

Pampalon, R., Hamel, D., Gamache, P., Philibert, M. D., Raymond, G., & Simpson, A. (2012). An area-based material and social deprivation index for public health in Québec and Canada. *Canadian Journal of Public Health / Revue Canadienne de Sante'e Publique*, *103*, S17–S22. https://doi.org/10.1007/bf03403824

Pearce, J., & Dorling, D. (2006). Increasing geographical inequalities in health in New Zealand, 1980–2001. *International Journal of Epidemiology*, *35*(3), 597-603. https://doi.org/10.1093/ije/dyl013

Pratschke, J., & Haase, T. (2015). A longitudinal study of area-level deprivation in Ireland, 1991–2011. *Environment and Planning B: Planning and Design*, *42*(3), 384–398. https://doi.org/10.1068/b130043p

Ribeiro, A. I., Fraga, S., Severo, M., Kelly-Irving, M., Delpierre, C., Stringhini, S., Kivimaki, M., Joost, S., Guessous, I., & Severi, G.

(2022). Association of neighbourhood disadvantage and individual socioeconomic position with all-cause mortality: A longitudinal multicohort analysis. *The Lancet Public Health*, *7*(5), e447–e457. https://doi.org/10.1016/S2468-2667(22)00036-6

Salmond, C., & Crampton, P. (2002). *NZDep2001 Index of Deprivation User's Manual.* Department of Public Health, Wellington School of Medicine and Health Sciences. https://www.otago.ac.nz/__data/assets/pdf_file/0031/318568/nzdep2001-index-of-deprivation-instruction-manual-020336.pdf

Salmond, C., Crampton, P., & Atkinson, J. (2007). *NZDep2006 index of deprivation*. Department of Public Health, University of Otago. https://www.otago.ac.nz/__data/assets/pdf_file/0027/317574/nzdep2006-index-of-deprivation-research-report-020348.pdf

Salmond, C., Crampton, P., & Sutton, F. (1998). *NZDep96: index of deprivation*. Health Services Research Centre, Victoria University of Wellington. https://www.otago.ac.nz/__data/assets/pdf_file/0033/318786/nzdep1996-index-of-deprivation-instruction-manual-020341.pdf

Salmond, C. E., & Crampton, P. (2012). Development of New Zealand's deprivation index (NZDep) and its uptake as a national policy tool. *Canadian Journal of Public Health/Revue Canadienne de Sante'e Publique*, *103*(8 Suppl 2), S7–S11. https://www.jstor.org/stable/41995682

Singh, G. K. (2003). Area deprivation and widening inequalities in US mortality, 1969–1998. *American Journal of Public Health*, *93*(7), 1137–1143. https://doi.org/10.2105%2Fajph.93.7.1137

Skapinakis, P., Lewis, G., Araya, R., Jones, K., & Williams, G. (2005). Mental health inequalities in Wales, UK: Multi–level investigation of the effect of area deprivation. *The British Journal of Psychiatry*, *186*(5), 417–422. PMID: 15863747. https://doi.org/10.1192/bjp.186.5.417

Statistics New Zealand. (2014). *Linking censuses: New Zealand longitudinal census 1981–2006*. https://www.stats.govt.nz/methods/linking-censuses-new-zealand-longitudinal-census-19812006

Tobias, M. I., & Cheung, J. (2003). Monitoring health inequalities: life expectancy and small area deprivation in New Zealand. *Population Health Metrics*, *1*(1), Article 2. https://doi.org/10.1186/1478-7954-1-2

Townsend, P. (1987). Deprivation. *Journal of Social Policy*, *16*(2), 125–146. https://doi.org/10.1017/S0047279400020341

Turrell, G., Patterson, C., Oldenburg, B., Gould, T., & Roy, M. A. (2003). The socio-economic patterning of survey participation and non-response error in a multilevel study of food purchasing behaviour: area-and individual-level characteristics. *Public Health Nutrition*, *6*(2), 181–189. PMID: 12675961. https://doi.org/10.1079/phn2002415

Ward, A. D., Trowland, H., & Bracewell, P. (2019). The Dynamic Deprivation Index: Measuring relative socio-economic deprivation

in NZ on a monthly basis. *Kōtuitui: New Zealand Journal of Social Sciences Online*, *14*(1), 157–176. https://doi.org/10.1080/1177083X.2019.1578807