Air Quality and Social Inequity in Aotearoa: A Preliminary Assessment

14 November 2023

Authors:

Lou Wickham, Jayne Metcalfe & Kylie Mason

PREPARED FOR: **Te Whatu Ora**

CLIENT REPORT No: **FW23021**

REVIEWED BY: **Rachael Nicoll**

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Ministry of Health who funded this study and Patrick Hipgrave (EHINZ) who prepared the maps. The authors also wish to acknowledge the government agencies who funded the Health and Air Pollution in New Zealand (HAPINZ 3.0) study and provided the baseline data that made this study possible. These include the Ministry for the Environment, Te Manatū Waka Ministry of Transport, Waka Kotahi NZ Transport Agency, Ministry of Health, Tatauranga Aotearoa Statistics New Zealand and all regional councils of New Zealand.

Manager

Jan Powell

Science Leader, ESR

Co-Author

Lou Wickham

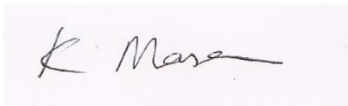
Director
Emission Impossible Ltd

Co-Author

Jayne Metcalfe

Director
Emission Impossible Ltd

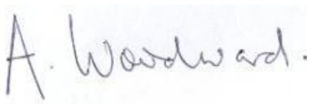
Co-Author



Kylie Mason

Environmental Health Intelligence
New Zealand

Peer reviewer



Alistair Woodward

Professor - Medical
Faculty of Medical & Health
Sciences, Univ. of Auckland

Peer reviewer

Claire Salter

Public Health Medicine
Registrar
ESR

Peer reviewer

Rachael Nicoll

Senior Air Quality Specialist
Emission Impossible Ltd

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES CONTINUED

EXECUTIVE SUMMARY

This report outlines a preliminary investigation into social inequity of air quality exposure and associated impacts in New Zealand.

The Health and Air Pollution in New Zealand (HAPINZ 3.0) study (Kuschel *et al.* 2022) estimates that, in the year 2016, about one in three New Zealanders (31%) were exposed to annual levels *above* the WHO guideline for nitrogen dioxide (NO_2). We found that this exposure was not shared evenly when stratified by the New Zealand Deprivation Index (NZDep2013):

- The percentage of people living in the most socioeconomically deprived areas (NZDep2013 decile 10) exposed to annual concentrations of NO_2 above the WHO AQG is three times greater than the percentage of people living in the least socioeconomically deprived areas (NZDep2013 decile 1).
- On average, people living in NZDep2013 decile 10 areas were exposed to long-term concentrations of NO_2 that were 34% higher than people living in NZDep2013 decile 1 areas.

The HAPINZ 3.0 study also estimates that, in the year 2016, the majority of New Zealanders (81%) were exposed to annual levels *above* the WHO guideline for particulate matter less than 2.5 micrometres in diameter ($PM_{2.5}$). We found that this exposure did not vary significantly by socioeconomic deprivation.

Our preliminary investigation of chronic exposure by ethnic group found some key differences for NO_2. For example, at the national level, Asian people (10.5 µg/m^3), Pacific peoples (9.9 µg/m^3) and Middle Eastern / Latin American / African (MELAA) ethnic groups (9.9 µg/m^3) have higher population-weighted annual average exposure to NO_2 compared with European Only (7.3 µg/m^3). Māori (7.1 µg/m^3) had similar chronic exposure to the European Only group.

We explored whether this disparity might be due to these ethnic groups living in urban areas, in particular Auckland where 67% of the urban population is exposed to annual NO_2 above the WHO guideline (10 µg/m^3). We found that disparities in exposure to NO_2 between different ethnic groups reduced within urban areas, particularly in Auckland. For example, in urban Auckland, population-weighted annual average exposures to NO_2 for Asian (11.9 µg/m^3), MELAA (11.8 µg/m^3), Pacific peoples (11.7 µg/m^3) and Māori (11.1 µg/m^3) are somewhat higher than for European Only (10.7 µg/m^3). Therefore our analysis suggests that the disparity in exposure for different ethnic groups is strongly influenced by some ethnic groups living predominantly in urban areas.

However, some disparities remain in other New Zealand cities, in particular with Asian and MELAA ethnic groups (and to a lesser extent, Pacific peoples and Māori) typically having higher population-weighted annual average exposure to NO_2 than the European Only group in some cities (for example, Christchurch and Dunedin).

In addition to exploring differences in exposure to air pollution, we used the HAPINZ 3.0 model to quantitatively estimate health impacts associated with exposure to long-term pollution. We looked at how these estimated health impacts differed in relation to socioeconomic deprivation.

We found that estimated air pollution health impacts associated with both anthropogenic $PM_{2.5}$ and NO_2 exposure were substantially higher in more deprived areas. For example, in the most deprived areas (NZDep2013 decile 10) compared with the least deprived areas (NZDep2013 decile 1), the:

- rate of premature mortality (30 years +) associated with exposure to NO_2 and $PM_{2.5}$ is **two times higher**
- rate of respiratory hospitalisation associated with exposure to NO_2 is **four times higher**
- rate of respiratory hospitalisation associated with exposure to $PM_{2.5}$ is **three times higher**
- rate of cardiovascular hospitalisation associated with exposure to NO_2 and $PM_{2.5}$ is **1.7 times higher**
- rate of asthma prevalence in 0–18-year-olds associated with exposure to NO_2 is **1.6 times higher.**

This increase in health impacts from air pollution in more deprived areas can be explained by two factors:

(i) underlying structural inequities, specifically higher base health incidence rates of all health outcomes studied (mortality, respiratory & cardiovascular hospitalisations, childhood asthma prevalence) in more deprived areas; as well as

(ii) higher levels of exposure to air pollution in more deprived areas, and thus a higher proportion of health impacts due to air pollution.

This means that air pollution health impacts will be worse in more deprived areas due to a combination of higher pollutant concentration in these areas **and** the higher base health incidence rates.

Overall, the data show that people in areas of higher socioeconomic deprivation are adversely affected more strongly by air pollution. This means policy that targets air pollution improvements in areas of higher socioeconomic deprivation would deliver bigger health benefits, especially policy to reduce motor vehicle emissions (the main source of NO_2).

Of note, we found the greatest health impacts, in both relative and absolute terms, were associated with chronic exposure to NO_2. These impacts vary by geography, with the Counties Manukau District Health Board area disproportionately impacted compared with all other areas in New Zealand.

It is important to note that we have made no adjustments for age, gender, ethnicity or smoking in this preliminary analysis of health impacts.[1] This means that the findings may alter if more comprehensive analyses are carried out.

[1] The exposure response functions used to estimate health impacts do address confounding factors including age, sex, ethnicity, income, education, smoking status and ambient temperature, in a New Zealand context (Hales et al., 2021).

1. Introduction

In 2022 Kuschel *et al*. published the Health and Air Pollution in New Zealand (HAPINZ) 3.0 study. This multidisciplinary, national study found that despite relatively low levels of air pollution in New Zealand versus many other countries, the health burden associated with air pollution is still appreciable.

It is also known that, in general, people who live in more socioeconomically deprived areas are more susceptible to environmental risks.[2] However, the relationship between areas of higher socioeconomic deprivation and air pollution exposure and health impacts has not been specifically explored in New Zealand.

This study uses HAPINZ 3.0 estimates of sub-national population exposure to chronic air pollution; specifically, long-term concentrations of $PM_{2.5}$ and nitrogen dioxide (NO_2) to consider:

> *How does population exposure to air pollution, and associated health impacts, vary in New Zealand?*

We also explored whether exposure to air pollution varies with ethnicity, however associated health impacts were not explored in this preliminary analysis.

[2] https://www.ehinz.ac.nz/indicators/population-vulnerability/socioeconomic-deprivation-profile/

2. Methodology

This study investigates geographical and social determinants of population exposure to key pollutants $PM_{2.5}$ and NO_2 in New Zealand. The focus is on long-term exposure (i.e., annualised concentrations) as the epidemiology is clear that more people are adversely affected, more seriously, through chronic exposure than through short-term exposure (WHO, 2021).

This study uses the HAPINZ 3.0 health effects model (Sridhar *et al.* 2022)[3] provided through the Health and Air Pollution in New Zealand 3.0 Study (Kuschel *et al.* 2022). This model has a base year of 2016 (2015-2017 health incidence and air quality monitoring data) as that was the latest health data available at the time of the study.

2.1 GEOGRAPHICAL DISAGGREGATION

This study utilises base health incidence (case) data and ambient air quality data provided in the HAPINZ 3.0 study (Kuschel et al. 2022). The HAPINZ 3.0 study was disaggregated geographically to 2013 census area units and 20 district health board (DHB) areas as shown in **Figure 1**.

We note that on 1 July 2022, the district health boards were dissolved and amalgamated into Te Whatu Ora – Health New Zealand.

Urban areas in New Zealand cities were defined as main, secondary or minor urban areas as detailed in Kuschel et al., 2022.

2.2 NEW ZEALAND DEPRIVATION INDEX

The New Zealand Deprivation Index 2013 (NZDep2013) combines census data relating to income, home ownership, employment, qualifications, family structure, housing, access to transport and communications (Atkinson et al. 2014). NZDep2013 groups deprivation scores of small areas into deciles, where decile 1 represents the areas with the least deprived scores and decile 10 the areas with the most deprived scores. An area in decile 10 therefore indicates that the area is in the most deprived 10% of areas in New Zealand.

Figure 2 shows NZDep2013 by 2013 census area units.[4] **Figure 3** further illustrates how socioeconomic deprivation varies geographically in New Zealand, comparing the relative populations in each NZDep2013 decile in Counties Manukau and Canterbury district health boards.

It is important to note that NZDep2013 estimates the *relative* socioeconomic deprivation of an area and does not directly relate to the prevalence of absolute poverty affecting individuals. This means that the index cannot be used to look at changes in absolute deprivation over time as 10% of areas will always be the most deprived, relative to other areas in New Zealand.

Additionally, it should be noted that NZDep is very ethnically patterned in New Zealand (Loring et al. 2022), with Māori and Pacific peoples over-represented in more socioeconomically deprived areas.

Appendix A presents the percentage of population in each NZDep2013 for all DHBs.

[3] Available online: https://www.ehinz.ac.nz/projects/hapinz3/explore-publications-and-data/

[4] Further details of the NZDep2013 Index of Deprivation are available on the Otago University website: https://www.otago.ac.nz/wellington/departments/publichealth/research/hirp/otago020194.html

FIGURE 1: District health board areas in this study [Source: Curtis et al., 2020]

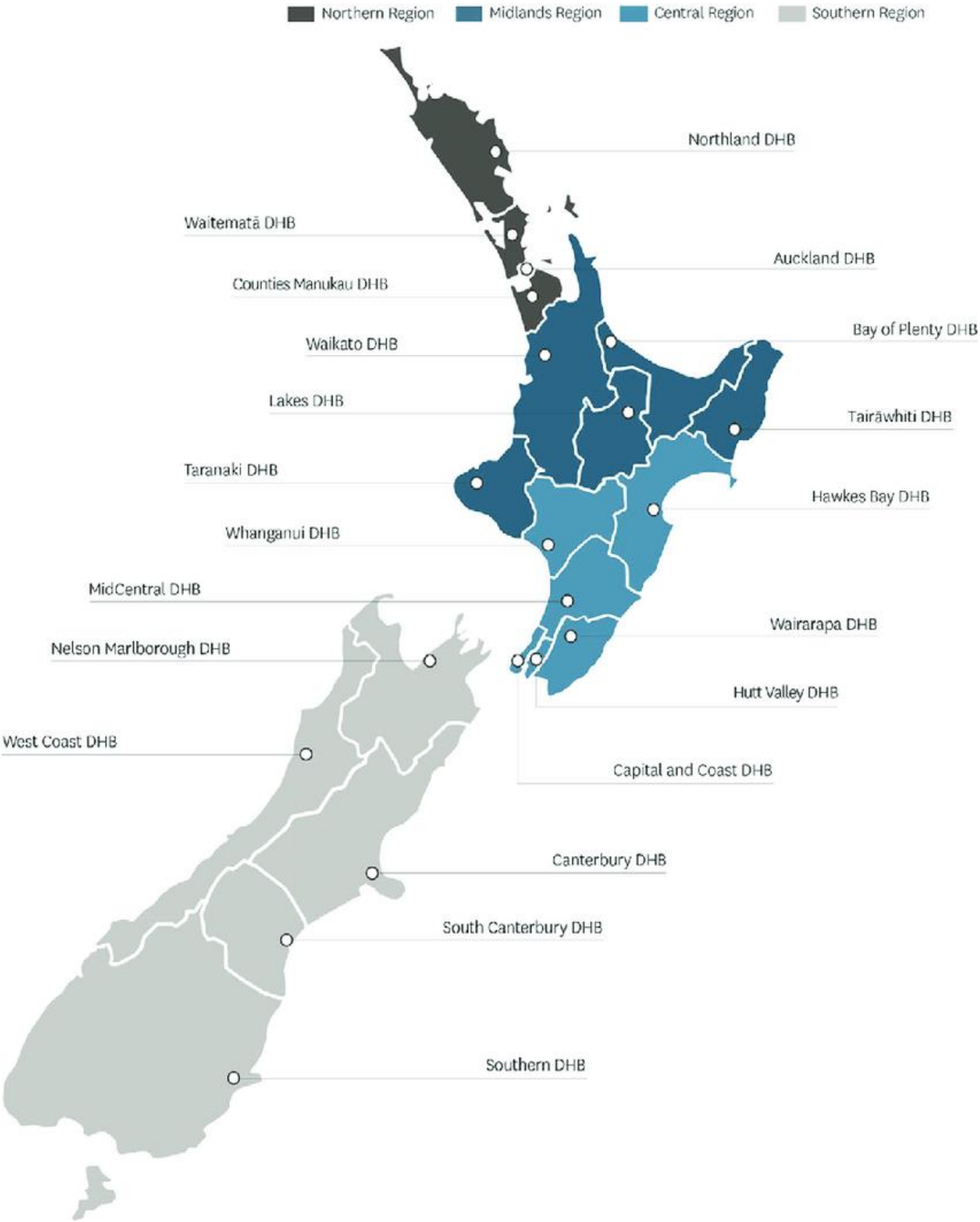


FIGURE 2: NZDep2013 deciles by 2013 census area unit with enlarged detail for Auckland and Christchurch [Source: EHINZ]

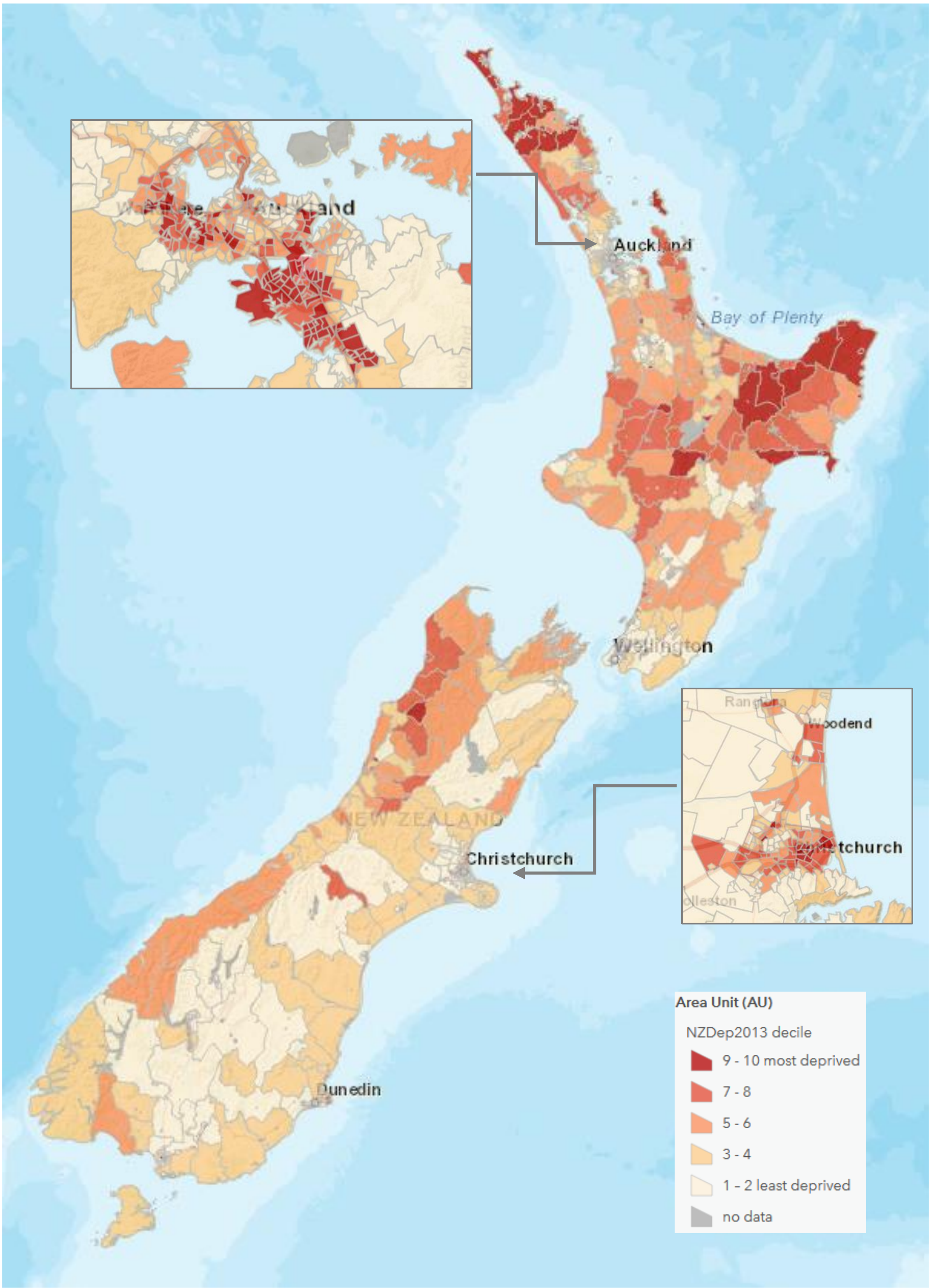
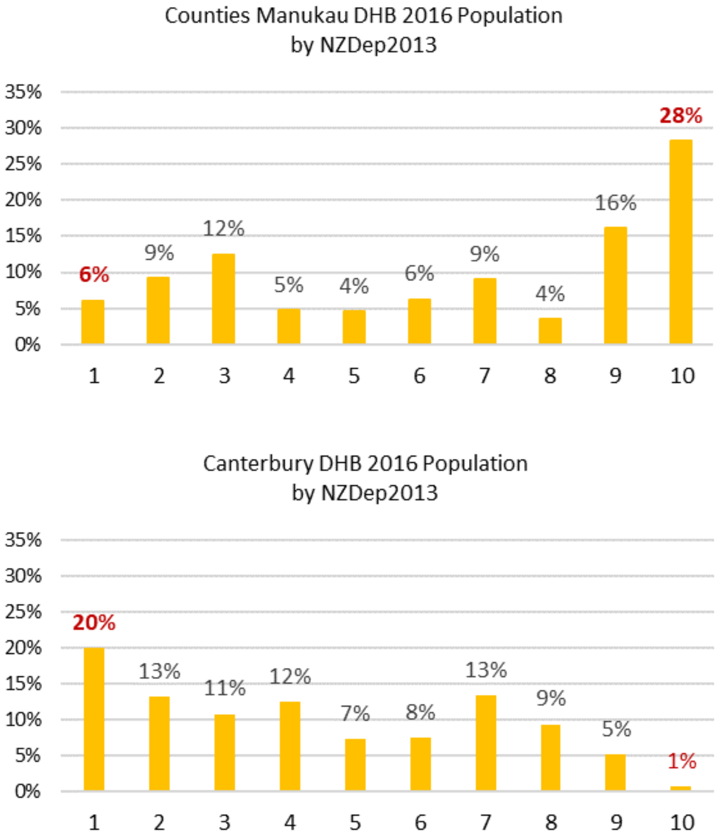


FIGURE 3: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis) for Counties Manukau DHB (top) and Canterbury DHB (bottom)



NZDep2013 decile (1 = least deprived, 10 = most deprived)

2.3 ETHNICITY DATA

The purpose of this research is to investigate equity, or lack thereof, for all ethnic groups air pollution exposure in New Zealand. Accordingly, the modified total response ethnic group classification (Yao et al, 2022) has been used in this study. This method categorises the following ethnic groups as follows:

- Total response ethnic groups for Māori, Pacific peoples, Asian, MELAA (Middle Eastern/Latin American/African) and Other ethnic groups (i.e., these ethnic groups include everyone who identified as the ethnicity), to best represent these population groups
- European Only, as the comparator group (which only includes people who solely identified with European ethnicity).

The modified total response ethnicity approach has been shown to represent each ethnic group (Māori, Pacific peoples, Asian, MELAA) well by using total response ethnic groups, while also providing a non-overlapping comparator group (European Only). This approach allows examination of equity for Māori as guaranteed by Te Tiriti o Waitangi (Treaty of Waitangi), as well as allowing assessment of inequities for other ethnic groups (such as Pacific peoples and Asians) (Yao et al, 2022). Comparisons can only be made between the European Only and other ethnic groups, not between the other ethnic groups themselves because there will be some people who are included in both groups, and therefore the groups are not mutually exclusive.

Accordingly, ethnicity data used in this study are based on total response ethnic groups (and sole European for the 'European Only' group), using usually resident population data from the 2013 census, as this was the most recent data available by (2013) census area unit. We have not adjusted the 2013 ethnicity population data to align with the base year for the HAPINZ 3.0 study (2016).[5]

Note on health impacts of air pollution:

It is well established that there are stark patterns of inequity in socioeconomic deprivation between Māori and European Only ethnic groups in New Zealand (Loring et al. 2022). This has led to stark patterns of inequity in the underlying health incidence data (refer section 4.1 base health incidence data).

We have <u>not</u> assessed health impacts by ethnicity as the HAPINZ model does not incorporate age-standardised health incidence data (refer section 2.5 model limitations).

2.4 HEALTH IMPACTS

This study estimates the relative impacts of air pollution for people living in New Zealand by NZDep2013 decile. As noted above, this analysis utilised the national exposure model in the Health and Air Pollution in New Zealand 3.0 study (Sridhar *et al.* 2022).

The air pollution health burdens are calculated in HAPINZ 3.0 for each census area unit, as follows:

Health Effects (cases) = Cases (total) × PAF

where:

Health effects (cases) are the number of premature deaths, hospital admissions or restricted activity days (depending on the health outcome being assessed) attributed to air pollution.

Cases (total) is the total number of health cases (premature deaths, hospital admissions, or for restricted activity days, population) in the area of interest (i.e., health incidence data based on analysis of Ministry of Health mortality and hospitalisations datasets by census area unit).

PAF (population attributable fraction) is the estimated percentage of total health cases that are attributable to the air pollution exposure.

The PAF is calculated using the following formula, adapted from Prüss-Üstün *et al* (2003):

$$\mathbf{PAF} = \frac{(\mathbf{RR} - 1) \times \mathbf{E}}{[(\mathbf{RR} - 1) \times \mathbf{E}] + 1}$$

Where:

RR *(relative risk, also referred to as the exposure-response function)* shows the change in risk for a particular health outcome (e.g. premature death) per unit change in concentration of a particular air pollutant (e.g. 1.11 per 10 μg/m^3 of PM_{10}), based on epidemiological evidence

[5] CAU estimates of ethnic group populations were only available for the 2013 and 2018 Censuses (not between years). The HAPINZ 3.0 study used linear interpolation for 2013 and 2018 CAU data to estimate 2016 population data by ethnic group, but this analysis did not include all ethnic groups (Asian, MELAA) as assessed in this study.

E *(exposure)* is the concentration of pollutant in the area of interest (e.g. annual average PM_{10} concentration in a particular census area unit), in terms of the units of relative risk

Accordingly, health impacts are affected by the concentration of air pollution (which affects the PAF) as well as the total number of health cases in the location being assessed (base incidence).

2.5 MODEL LIMITATIONS

Comparisons of health impacts between different groups of people may be affected by important differences in demographics, such as age. Disease rates tend to be higher in older populations, simply due to effects of age. Important and inequitable differences between Māori and non-Māori mortality rates (Ministry of Health 2022, Walsh & Grey 2019) may not be evident in crude/unadjusted health incidence rates due to the younger population structure of the Māori population. Such differences are typically accounted for in analysis of health data by "standardising" data between different groups (for example, by standardising by age). [6]

In this preliminary analysis of health impacts, we have made no adjustments for age, gender, ethnicity or smoking. This means that the findings may alter if more comprehensive analyses are carried out.

The HAPINZ 3.0 model has been internationally peer reviewed and supports a high degree of confidence for the base case (2016). The limitations of the HAPINZ 3.0 model are documented in full in the study itself and not repeated here (Kuschel et al. 2022).

2.6 NOTE ON WHO AIR QUALITY GUIDELINES

This study considers chronic exposure in New Zealand disaggregated by socioeconomic deprivation and ethnicity to two pollutants, NO_2 and $PM_{2.5}$. To date, New Zealand has no national environmental standards for *chronic* exposure to NO_2 or $PM_{2.5}$.

To inform this study, comparison is made with air quality guidelines (AQG) for NO_2 and $PM_{2.5}$ published by the World Health Organization (WHO, 2021). The WHO AQG offer quantitative health-based recommendations for air quality management for the purpose of reducing the unacceptable global health burden that results from air pollution. WHO notes that exceedance of the air quality guideline (AQG) levels is associated with important risks to public health (WHO, 2021). Further details of health effects associated with each pollutant are documented in the guidelines which are available online (www.who.int).

Although the WHO guidelines have no regulatory status in New Zealand, they are designed to offer guidance in reducing the health impacts of air pollution based on expert evaluation of current scientific evidence.

[6] The numbers of deaths per 100,000 population are influenced by the age distribution of the population. Two populations with the same age-specific mortality rates for a particular cause of death will have different overall death rates if the age distributions of their populations are different. Age-standardised mortality rates adjust for differences in the age distribution of the population by applying the observed age-specific mortality rates for each population to a standard population.

3. PRELIMINARY RESULTS: EXPOSURE

This section explores whether population exposure to air pollution varies in New Zealand by socioeconomic deprivation and/or ethnic group.

Exposure has been defined by comparing the estimated population-weighted annual average concentrations with the global air quality guidelines (AQG) published by the World Health Organisation (WHO, 2021).

3.1 NATIONAL

Figures 4 and **5** present the national population-weighted annual average concentrations of NO_2 and $PM_{2.5}$ (y-axis) stratified by NZDep2013 deciles (x-axis) for a base year 2016.

Figure 4 shows that exposure to NO_2 is generally higher in areas with higher levels of deprivation. We found that, on average, people living in the most deprived areas (NZDep2013 decile 10) are exposed to NO_2 levels 34% higher than people living in the least deprived areas (NZDep2013 decile 1) (8.7 vs 6.5 µg/m^3).

Figure 5 shows that, on average, the population-weighted annual average exposure to $PM_{2.5}$ is similar across NZDep2013 deciles when looking at the national-level data. However, it is also notable that population-weighted annual average levels of $PM_{2.5}$ at a national-level are elevated for *all* deciles compared with the WHO AQG for $PM_{2.5}$.

FIGURE 4: 2016 Population-weighted annual average concentration of NO_2 (μg/m³ on y-axis) by NZDep2013 deciles compared with WHO AQG of 10 μg/m³.

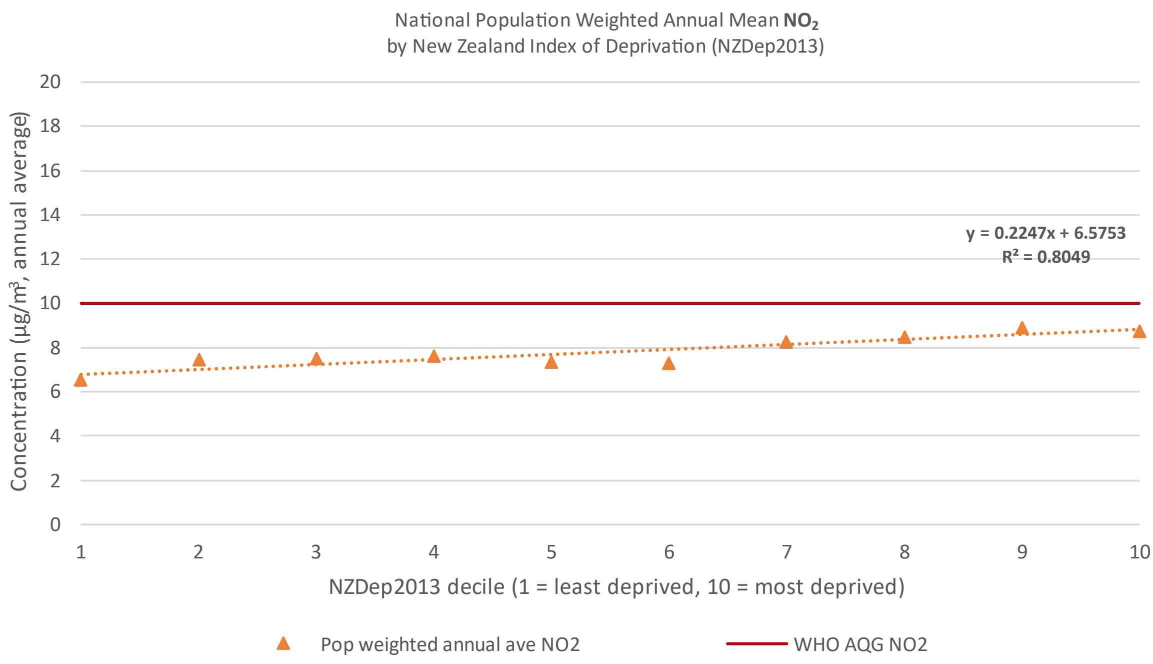
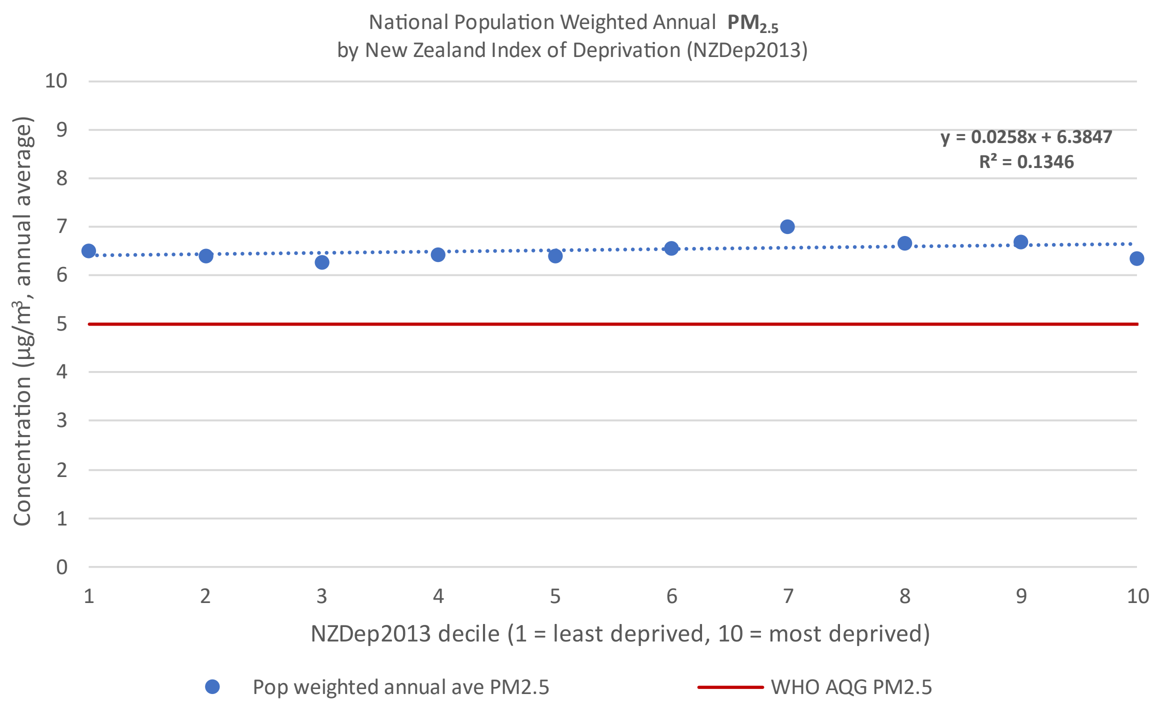


FIGURE 5: 2016 Population-weighted annual average concentration of $PM_{2.5}$ (μg/m³ on the y-axis) by NZDep2013 deciles compared with WHO AQG of 5 μg/m³.



3.2 DISTRICT HEALTH BOARD

Table 1 presents estimates of population-weighted annual average concentrations of NO_2 and $PM_{2.5}$ for each district health board for a base year 2016. Caution is needed in viewing the data as some district health boards cover wide geographic areas which can 'smooth' the exposure representation between rural and urban (e.g., Waikato and Southern DHBs). Noting this, Table 1 shows:

- Auckland, Counties Manukau, Waitematā and Canterbury District Health Boards have the highest population-weighted annual average concentrations of NO_2.
- Te Waipounamu (the South Island) District Health Boards have the highest population-weighted annual average concentrations of $PM_{2.5}$. Relatively high levels also occur in Lakes, Tairāwhiti and Hawke's Bay District Health Boards.

Figure 6 presents population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) by NZDep2013 deciles for all district health boards for a base year 2016, for comparison with WHO annual air quality guidelines. Figure 6 shows that population exposure to chronic pollution varies significantly around the motu (country). However, in general our analysis indicates that:

- Areas of higher socioeconomic deprivation tend to have the highest NO_2 concentrations. This was particularly true for the district health boards with the highest population-weighted annual average NO_2 concentrations (Auckland, Counties Manukau, Waitematā, Hawke's Bay and Canterbury District Health Boards).
- There is no clear relationship between $PM_{2.5}$ concentrations and socioeconomic deprivation in most district health boards. This is consistent with the exposure profile in the HAPINZ 3.0 model where $PM_{2.5}$ levels are relatively consistent across entire air sheds whereas NO_2 varies with distance from roads and industry.

Figure 7 and **Figure 8** present the percentage of population in each district health board exposed to each quintile of annual concentrations of NO_2 and $PM_{2.5}$ respectively for a base year 2016. Quintiles divide a dataset into five equal parts and are a useful way of comparing exposure as each quintile represents approximately 20% of the population across New Zealand. So, for example, approximately 20% of the New Zealand population is exposed to NO_2 concentrations in quintile 5 (the highest exposure quintile).

Figure 7 shows that elevated annual levels of NO_2 occur primarily in Auckland and Canterbury District Health Boards. By contrast, Figure 8 shows that elevated annual levels of $PM_{2.5}$ were present in all district health boards.

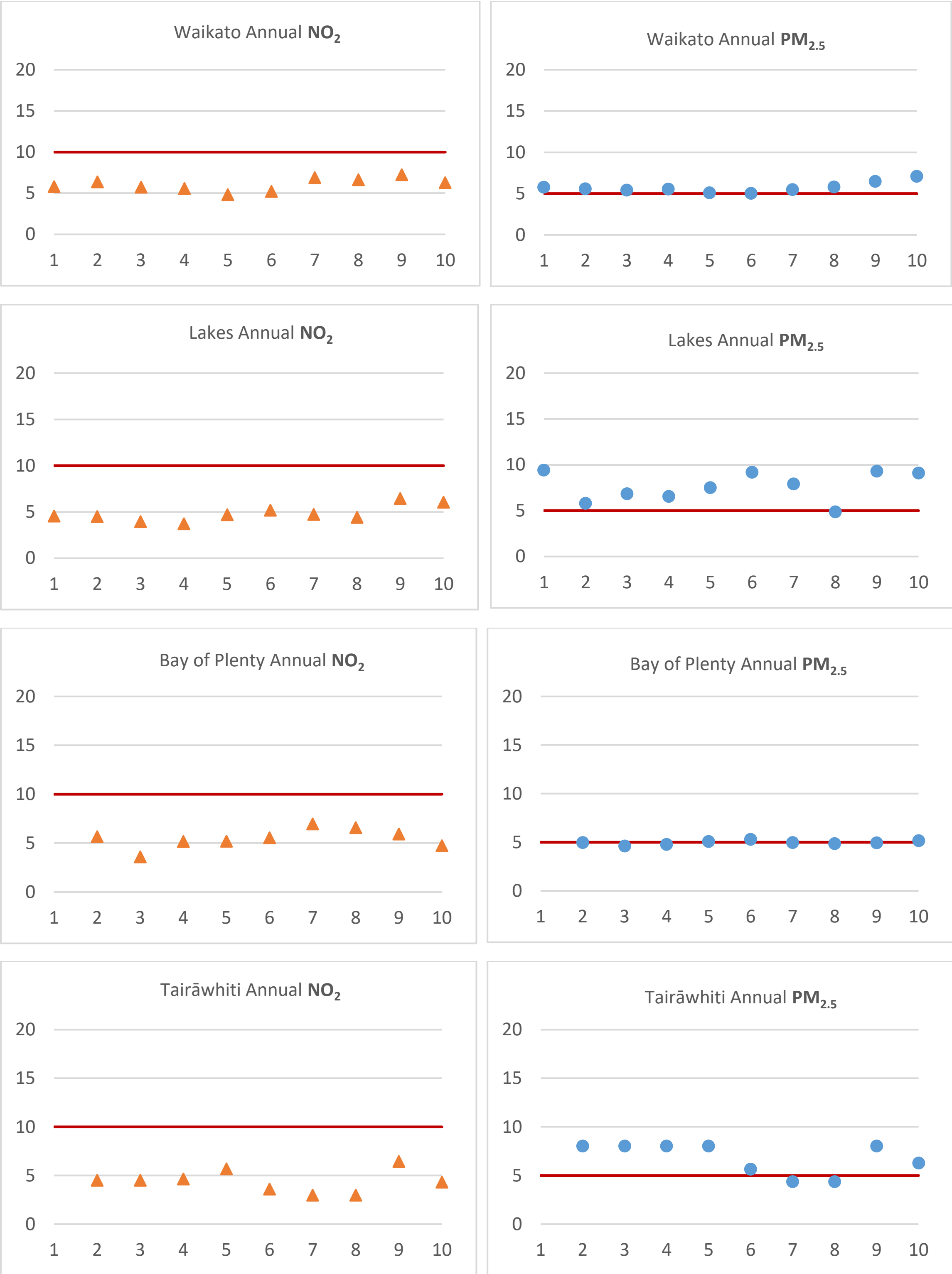
TABLE 1: 2016 Population-weighted annual average concentrations of NO_2 and $PM_{2.5}$ for each district health board area. [Source: Kuschel et al. 2022]. Darker shading indicates areas with higher concentrations for each pollutant.

District Health Board	Population (2016)	Population-weighted annual average concentration (µg/m^3)	
		NO_2	$PM_{2.5}$
New Zealand	**4,713,270**	**7.8**	**6.5**
Northland	176,310	4.3	5.2
Waitematā	588,355	8.5	5.6
Auckland	481,290	12.9	5.9
Counties Manukau	538,370	10.0	5.6
Waikato	402,005	6.2	5.8
Lakes	109,120	5.2	8.1
Bay of Plenty	232,805	5.7	5.0
Tairāwhiti	48,745	4.9	7.0
Taranaki	118,610	4.7	5.5
Hawke's Bay	166,790	7.6	7.3
Whanganui	65,040	5.4	5.8
MidCentral	176,385	5.6	5.7
Hutt Valley	149,550	5.9	5.5
Capital and Coast	307,375	6.6	5.7
Wairarapa	44,840	4.5	7.2
Nelson Marlborough	150,255	6.0	8.2
West Coast	32,920	3.9	8.0
Canterbury	540,950	9.8	9.1
South Canterbury	59,775	5.0	9.5
Southern	323,780	6.4	8.8
WHO Air Quality Guideline (annual)		**10**	**5.0**

FIGURE 6: Population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) (µg/m³ on the y-axis) by NZDep2013 deciles (1= least deprived, 10=most deprived on the x-axis) for all district health boards for a base year 2016. The red line shows the WHO annual average guideline (10 µg/m³ for NO_2 and 5 µg/m³ for $PM_{2.5}$).

NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure 6 continued: Population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) (μg/m^3 on the y-axis) by NZDep2013 deciles (1= least deprived, 10=most deprived on the x-axis) for all district health boards for a base year 2016. The red line shows the WHO annual average guideline (10 μg/m^3 for NO_2 and 5 μg/m^3 for $PM_{2.5}$).

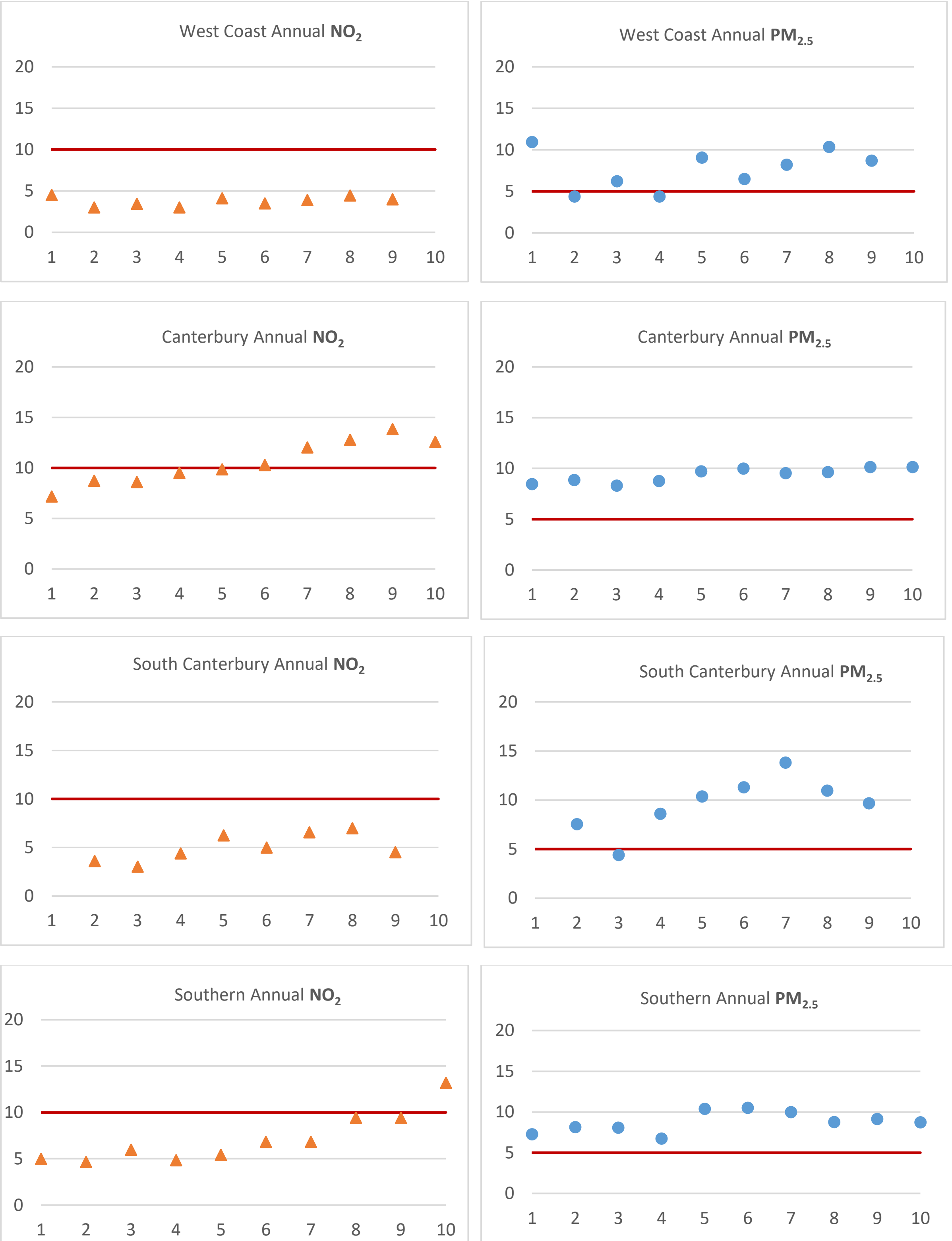


NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure 6 continued: Population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) ($\mu g/m^3$ on the y-axis) by NZDep2013 deciles (1= least deprived, 10=most deprived on the x-axis) for all district health boards for a base year 2016. The red line shows the WHO annual average guideline (10 $\mu g/m^3$ for NO_2 and 5 $\mu g/m^3$ for $PM_{2.5}$).

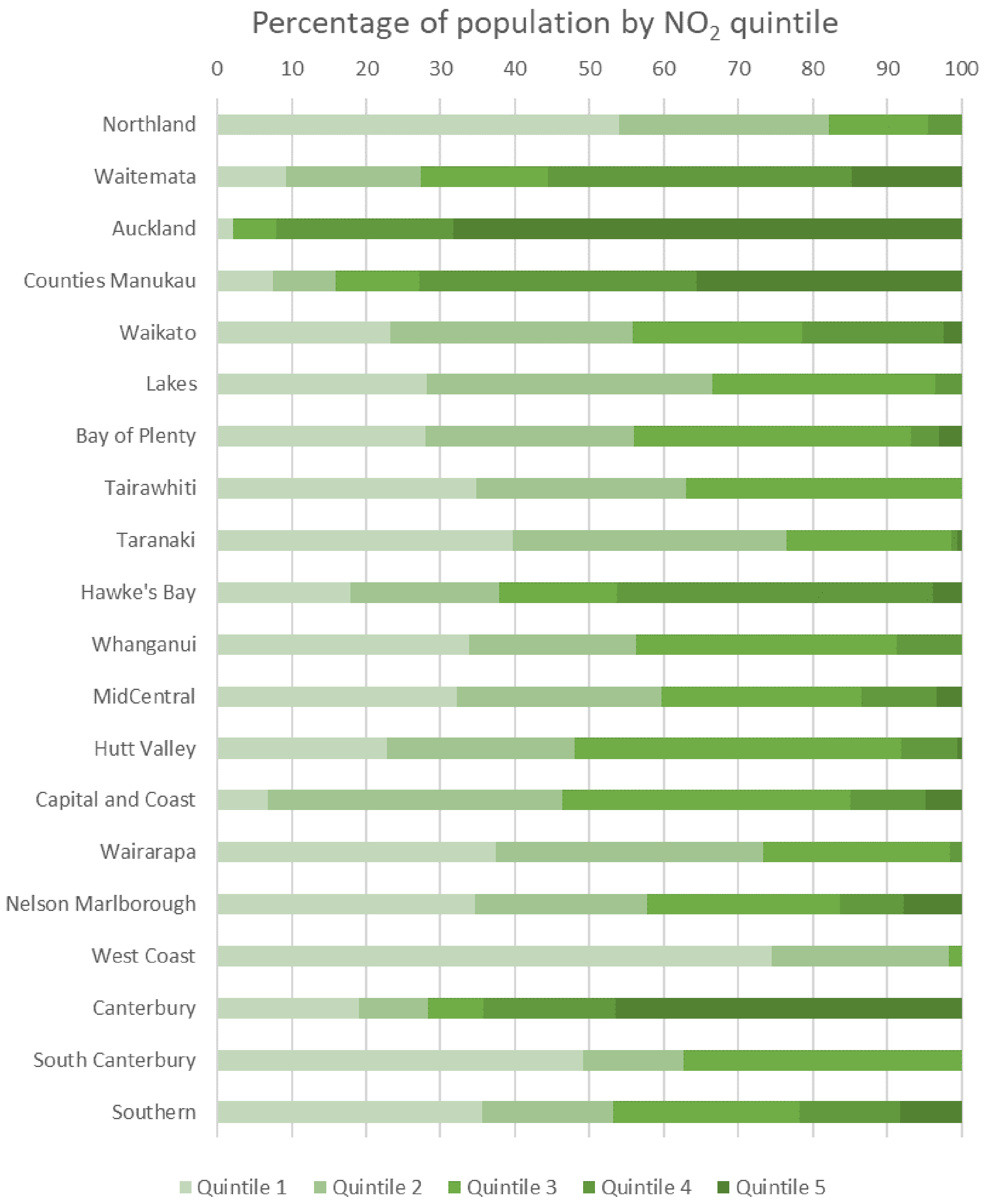
Figure 6 continued: Population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) (μg/m^3 on the y-axis) by NZDep2013 deciles (1= least deprived, 10=most deprived on the x-axis) for all district health boards for a base year 2016. The red line shows the WHO annual average guideline (10 μg/m^3 for NO_2 and 5 μg/m^3 for $PM_{2.5}$).

Figure 6 continued: Population-weighted annual average concentrations of NO_2 (left hand side) and $PM_{2.5}$ (right hand side) (µg/m^3 on the y-axis) by NZDep2013 deciles (1= least deprived, 10=most deprived on the x-axis) for all district health boards for a base year 2016. The red line shows the WHO annual average guideline (10 µg/m^3 for NO_2 and 5 µg/m^3 for $PM_{2.5}$).



NZDep2013 decile (1 = least deprived, 10 = most deprived)

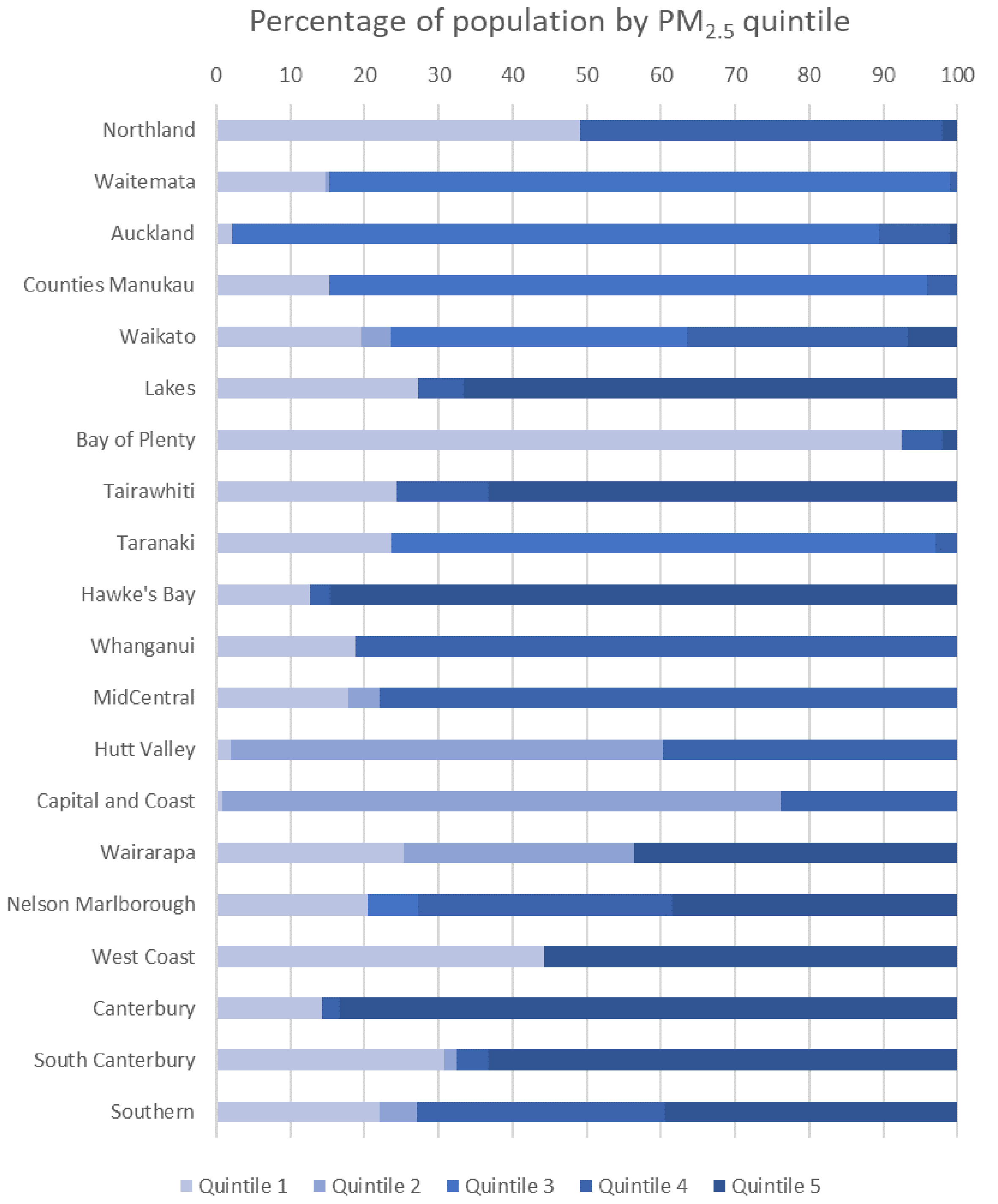
FIGURE 7: Percent population in each district health board by quintile NO_2 exposure for 2016 (refer key)



Key (WHO AQG for NO_2 = 10 µg/m^3)

NO_2	(µg/m^3)
Quintile 1	0 - 4.5
Quintile 2	4.5 - 5.2
Quintile 3	5.2 - 8.9
Quintile 4	8.9 - 12
Quintile 5	> 12

FIGURE 8: Percent population in each district health board by quintile $PM_{2.5}$ exposure for 2016 (refer key)



Key (WHO AQG for $PM_{2.5}$ = 5 µg/m^3)

$PM_{2.5}$	(µg/m^3)
Quintile 1	< 5.1
Quintile 2	5.1 - 5.6
Quintile 3	5.6 - 5.8
Quintile 4	5.8 - 7
Quintile 5	> 7

3.3 ELEVATED NO_2 AND NZDEP2013

We explored the relationship between chronic NO_2 exposure and the New Zealand Deprivation Index 2013 (NZDep2013) further by considering locations where the concentrations exceed the WHO air quality guideline (AQG) of 10 µg/m^3 for NO_2 as an annual average.

Figure 9 shows the number of people living in each NZDep2013 decile who are exposed to annual concentrations of NO_2 levels above the WHO AQG. If exposure were even across the deciles (as these deciles are assigned to roughly 10% of the population each) there would be no difference.

Figure 10 shows the percentage of population living in each NZDep2013 decile area who are exposed to annual concentrations of NO_2 levels above the WHO AQG. Figure 10 shows the percentage of people exposed to high annual concentrations of NO_2 (i.e., above the WHO AQG) is almost three times greater in NZDep2013 decile 10 areas (41%) than in decile 1 areas (15%).

Figure 11 presents the percentage of population who are exposed to annual concentrations of NO_2 above the WHO AQG by district health board. Auckland (85%), Counties Manukau (61%) and Canterbury (60%) have the highest percentage of their populations exposed to NO_2 levels above the WHO AQG.

Figure 12 provides more detail by presenting the number of people living in each NZDep2013 decile area who are exposed to NO_2 levels above the WHO AQG for each district health board. Counties Manukau stands out nationally as having the largest number of people (124,000) who live in the most deprived areas (NZDep2013 decile 10) and who are also exposed to NO_2 levels above the WHO AQG.

FIGURE 9: New Zealand population in areas where 2016 annual NO_2 levels exceed the WHO AQG of 10 µg/m^3 (y-axis) by NZDep2013 deciles (x-axis)

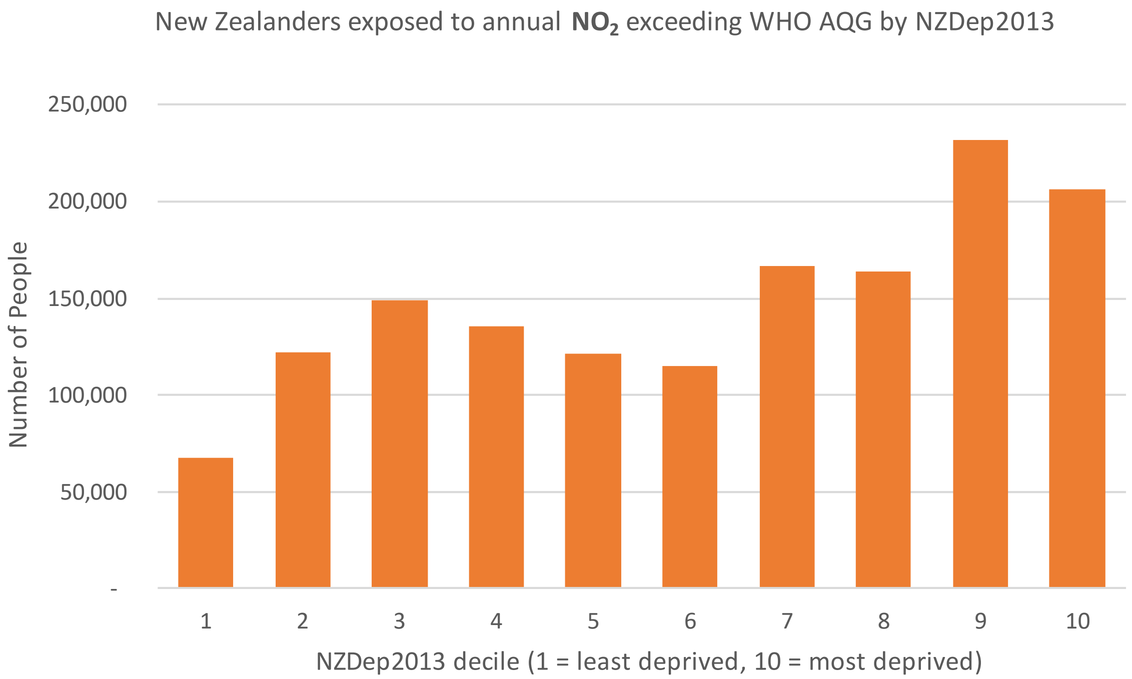


FIGURE 10: Percent New Zealand population in areas where 2016 annual NO_2 levels exceed the WHO AQG of 10 µg/m^3 (y-axis) by NZDep2013 decile (x-axis)

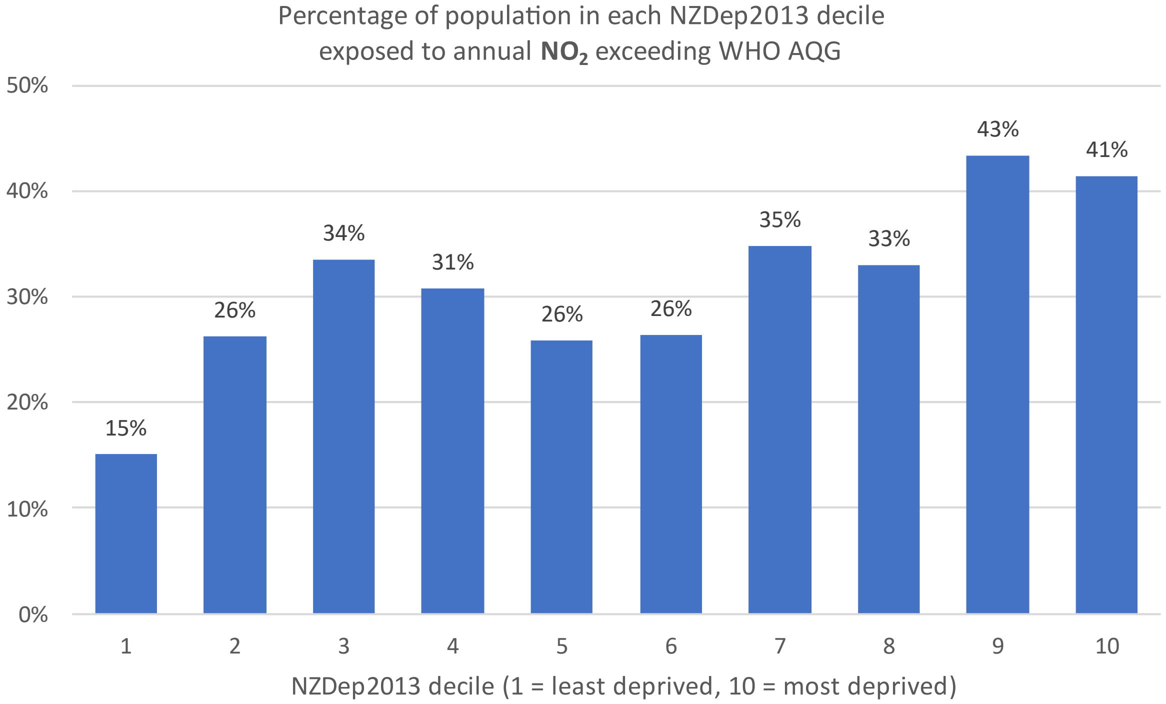


FIGURE 11: Percent population where 2016 annual NO_2 levels exceed the WHO AQG of 10 µg/m^3 (y-axis) by district health board (x-axis)

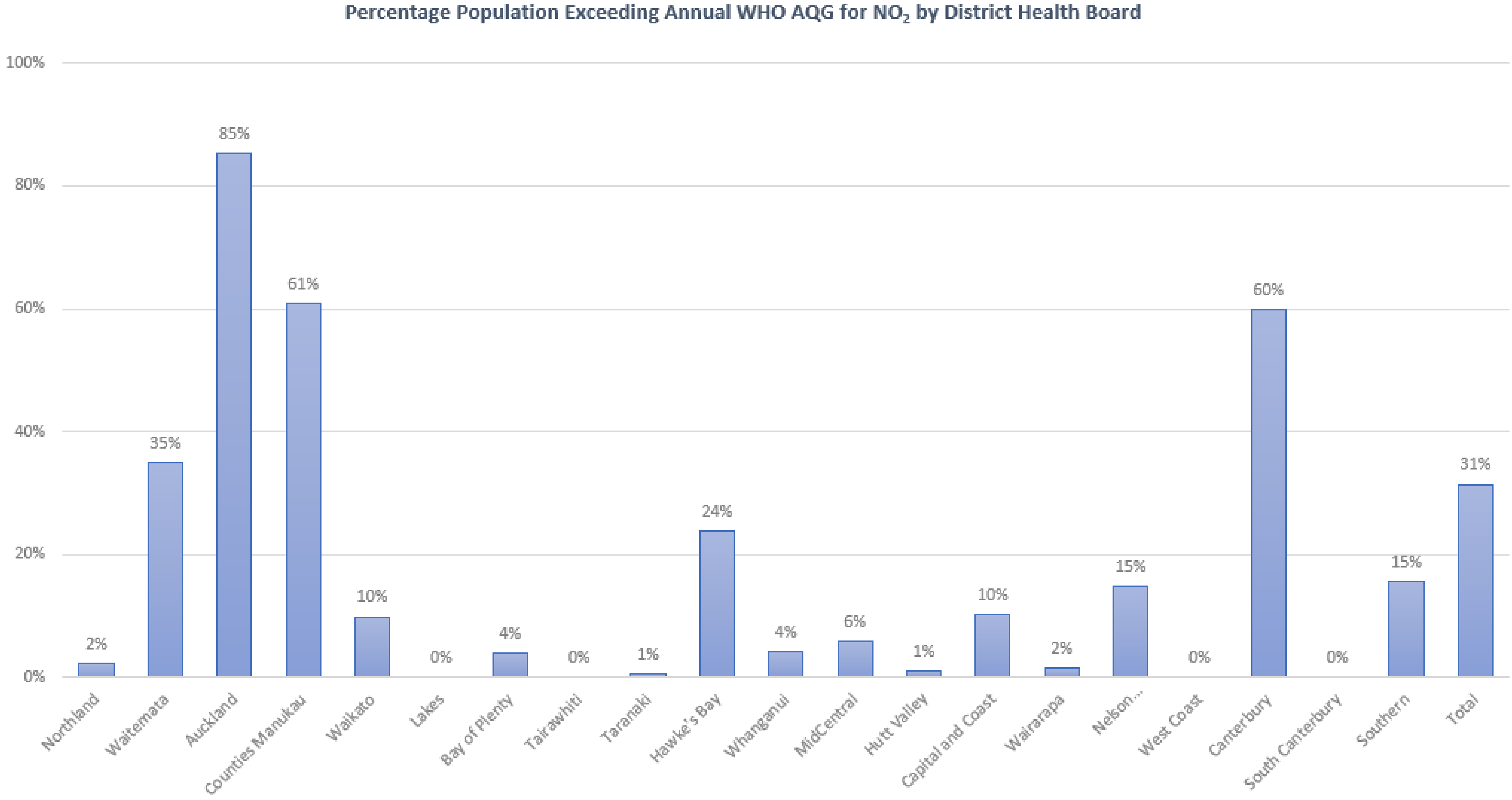
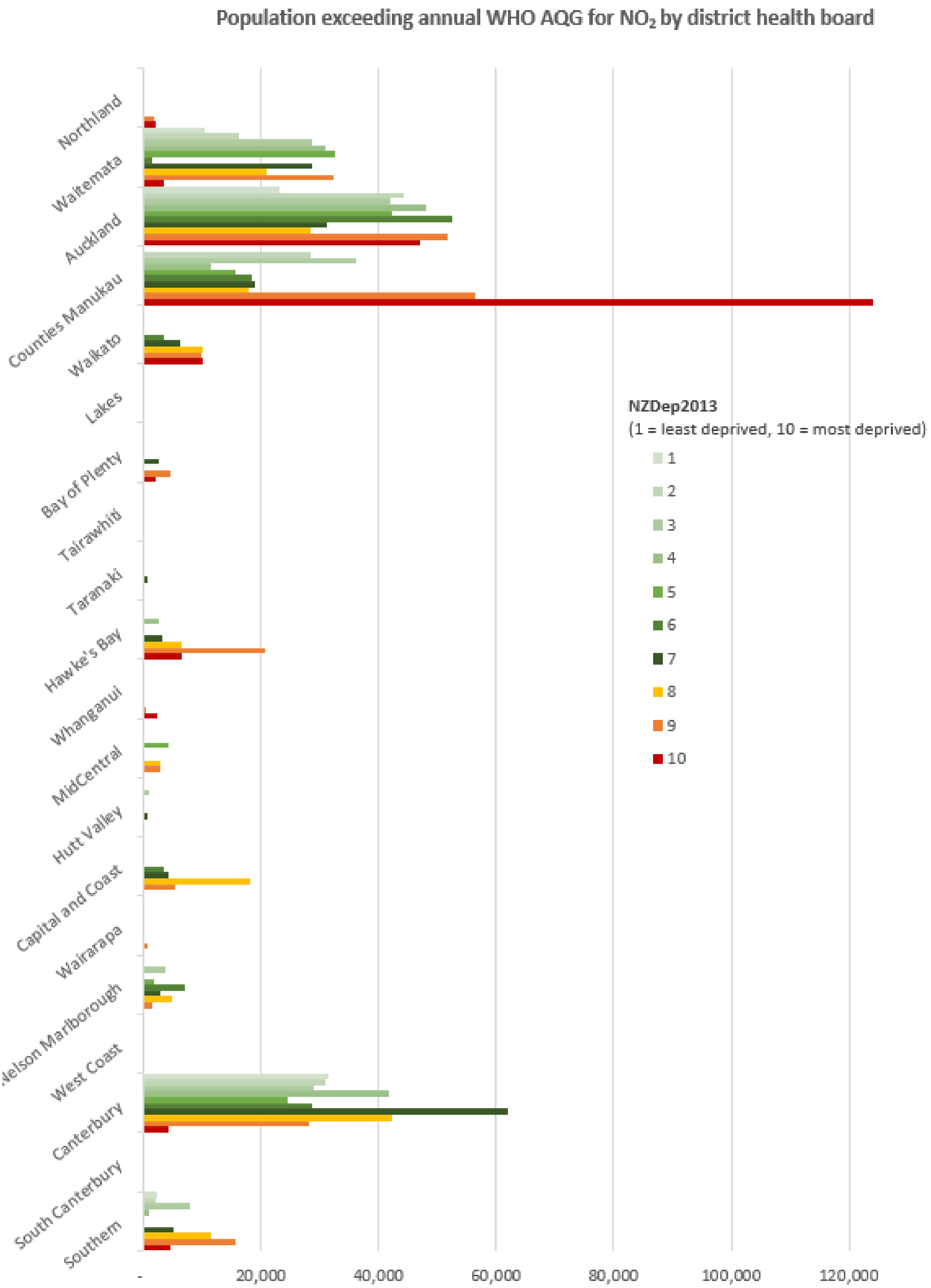


FIGURE 12: Number of people in areas where 2016 annual NO_2 levels exceed the WHO AQG of 10 µg/m^3 (x-axis) by NZDep2013 deciles in each district health board (y-axis)



3.4 URBAN EXPOSURE AND NZDEP2013: AUCKLAND CASE STUDY

Our analysis found that **on average** people living in more deprived areas are exposed to higher levels of NO_2 compared with people in less deprived areas. However, when we look at individual census area units, the relationship between exposure and deprivation is mixed.

Figure 13 presents a map of typical mid-week congestion on Auckland's roads. This clearly shows Auckland's motorways and major arterial routes which are the primary sources of NO_2.

Figure 14 presents a map of population-weighted annual average exposure to NO_2 (2016) for each census area unit in the Auckland urban area (left hand side) and NZDep2013 deciles for each census area unit in the Auckland urban area (right hand side). Exposure is colour coded by quintiles of exposure, with darker colours representing higher population-weighted annual average concentrations. NZDep2013 deciles are similarly colour coded with darker colours representing higher socioeconomic deprivation.

Whilst Figure 14 does appear to align the spatial distribution of annual NO_2 levels with heavily trafficked routes in Figure 13, the relationship between exposure and deprivation is mixed. For example, the isthmus (central Auckland) and north shore of Auckland have relatively elevated annual NO_2, but these areas tend to be relatively affluent. On the other hand, in the western and southern parts of Auckland, areas of higher socioeconomic deprivation tend to be in areas with higher chronic NO_2 exposure.

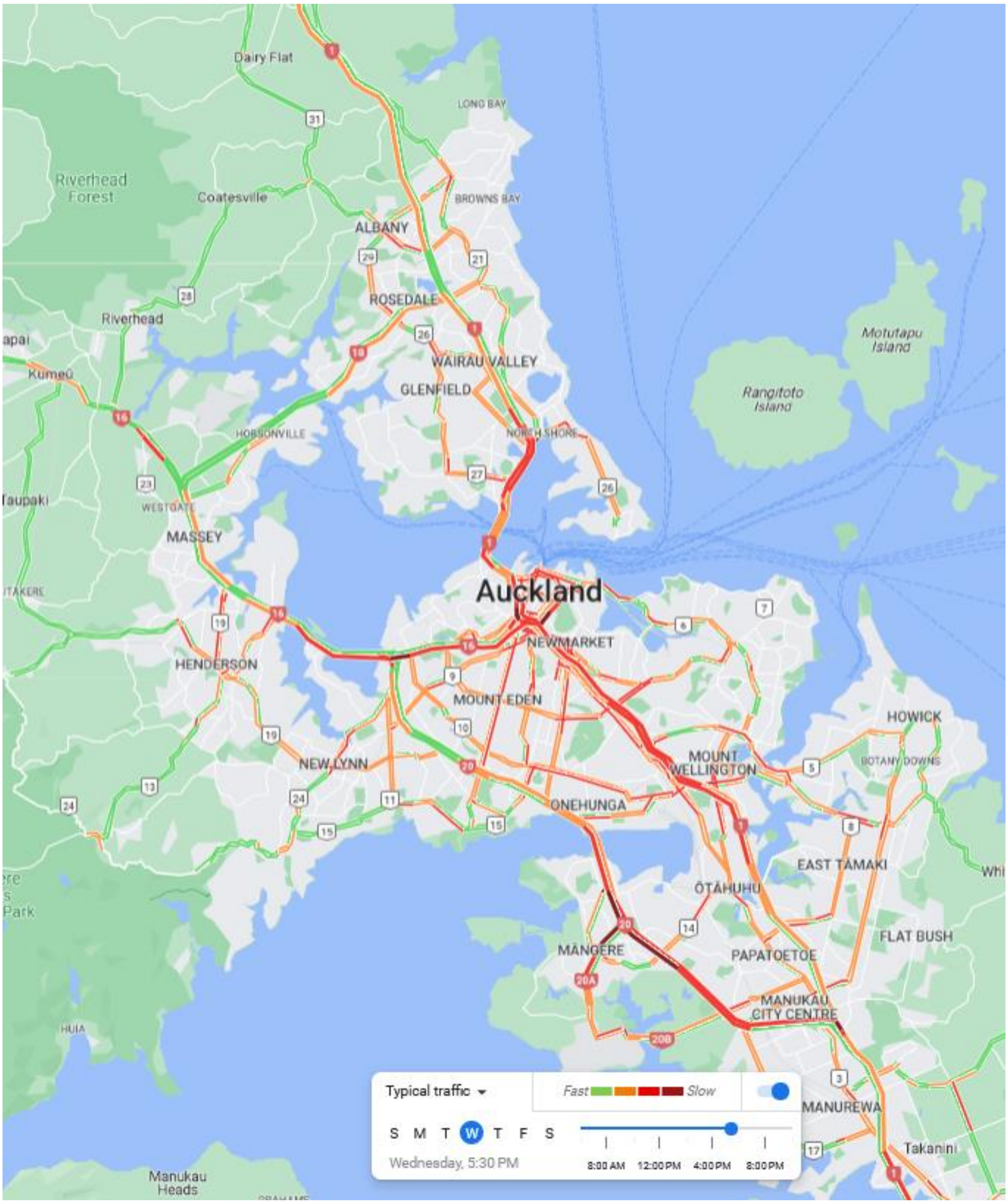
Figure 15 presents a map of census area units in urban Auckland that exceed the WHO air quality guideline for NO_2 (left hand side) and NZDep2013 deciles for each census area unit in the Auckland urban area (right hand side). This shows significant urban areas of Auckland are exposed to annual levels of NO_2 that cause harm to health.

The relationship between annual exposure to $PM_{2.5}$ and social deprivation is more uniform.

Figure 16 presents a map of population-weighted annual average exposure to $PM_{2.5}$ (2016) for each census area unit in the Auckland urban area (left hand side) and NZDep2013 deciles for each census area unit in the Auckland urban area (right hand side). This shows that chronic levels of $PM_{2.5}$ are ubiquitous across the Auckland isthmus with little disparity in exposure. This in turn, reflects the assumptions in the HAPINZ 3.0 national model which relied predominantly on ambient air quality monitoring data (whereas annual NO_2 was estimated using modelling as detailed in Kuschel *et al.*, 2022).

Figure 17 presents a map of census area units in urban Auckland that exceed the WHO air quality guideline for $PM_{2.5}$ (left hand side) and NZDep2013 deciles for each census area unit in the Auckland urban area (right hand side). This shows all urban areas of Auckland are exposed to annual levels of $PM_{2.5}$ that cause harm to health.

FIGURE 13: 'Typical' mid-week (5:30 pm, Wednesday) congestion on Auckland roads [Source: Google Maps, 2023] [7]



[7] https://www.google.com/maps/@-36.835877,174.7665296,11.46z/data=!5m1!1e1?entry=ttu Accessed 22 June 2023.

FIGURE 14: 2016 annual exposure to NO_2 (left hand side) and NZDep2013 deciles (right hand side) for Auckland urban areas by census area unit

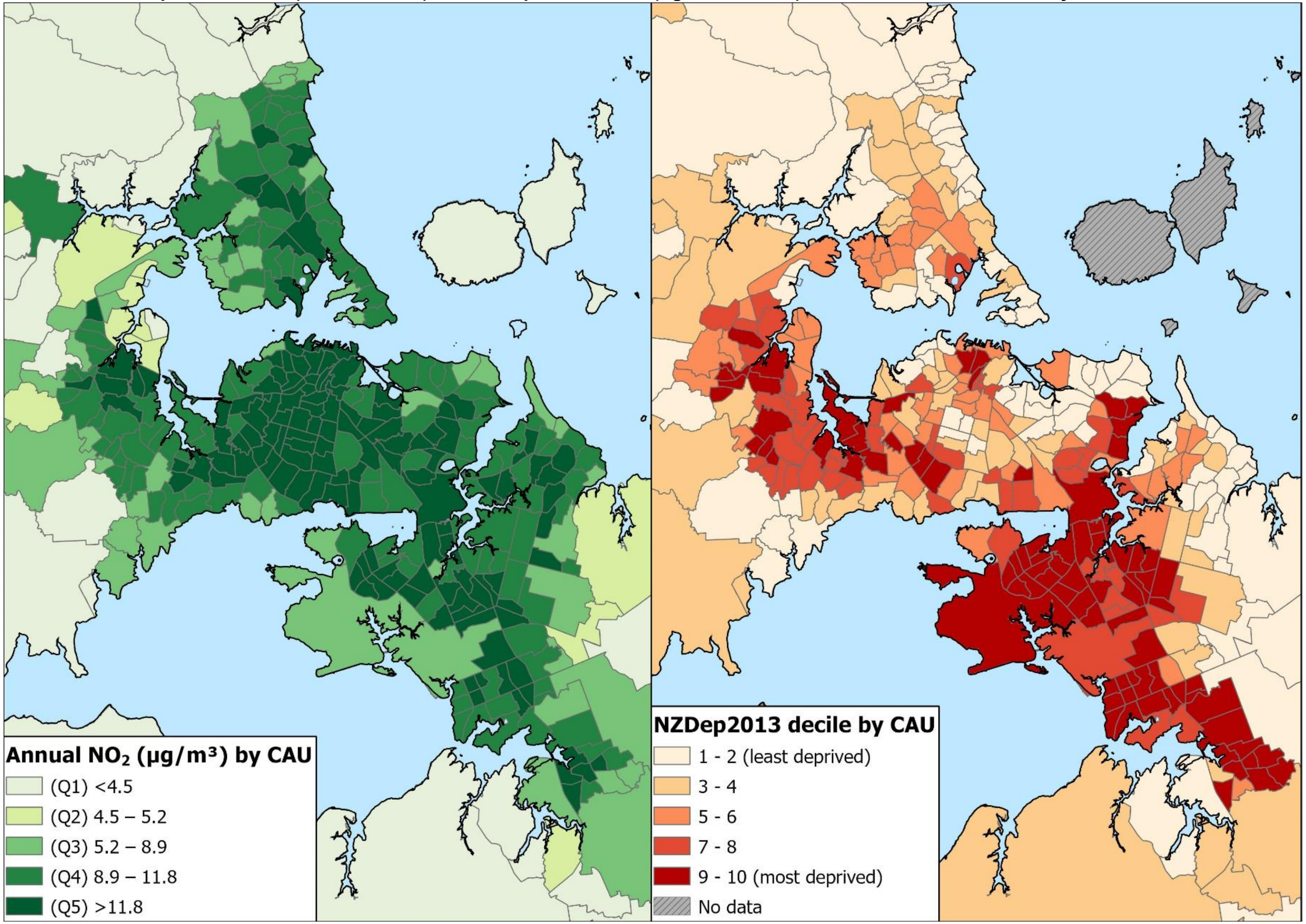


FIGURE 15: Locations in Auckland that exceed the WHO AQG for annual NO_2 (left hand side) and NZDep2013 deciles (right hand side) for Auckland urban areas by census area unit

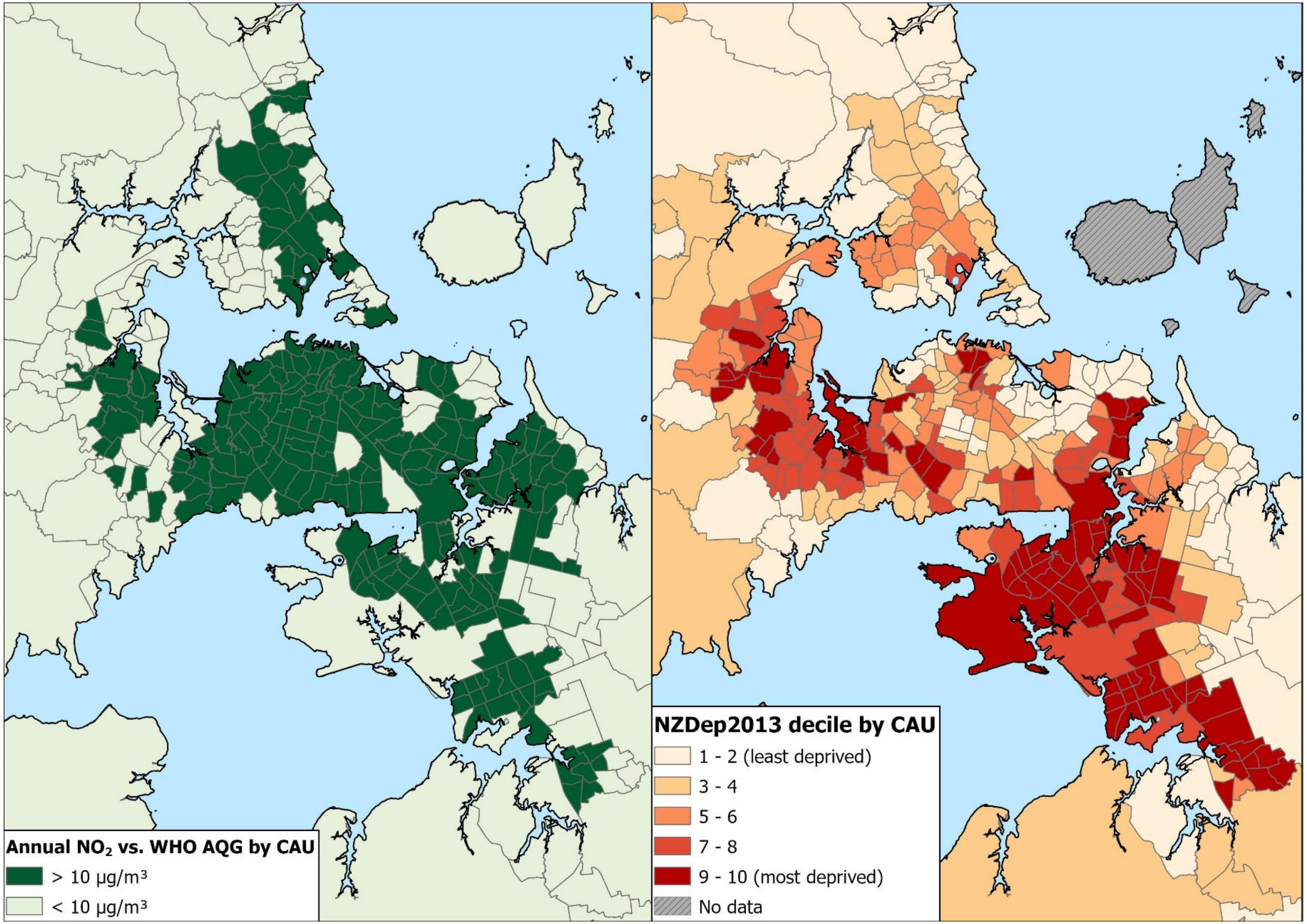


FIGURE 16: 2016 Annual exposure to $PM_{2.5}$ (left hand side) and NZDep13 deciles (right hand side) for Auckland urban areas by census area unit

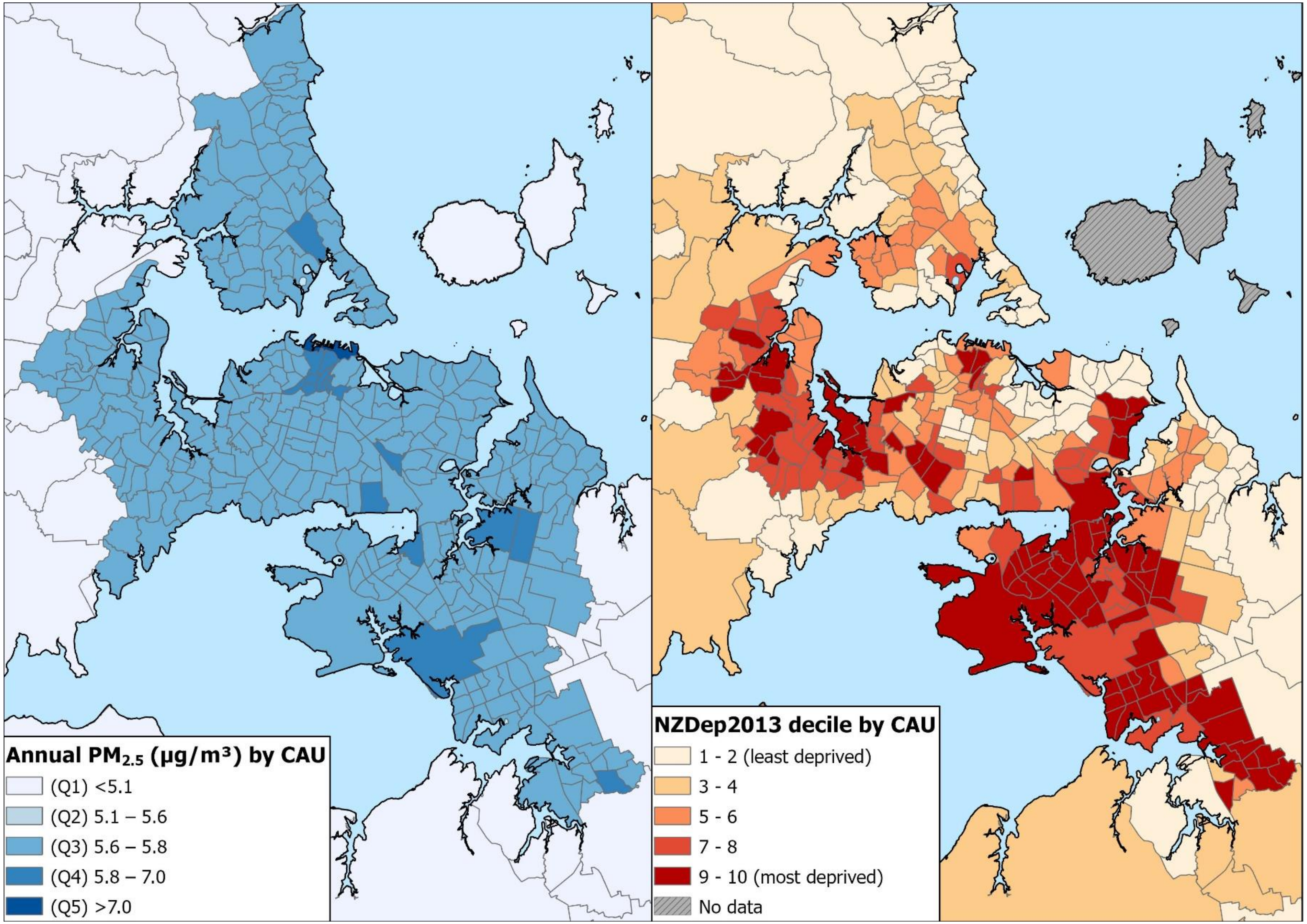
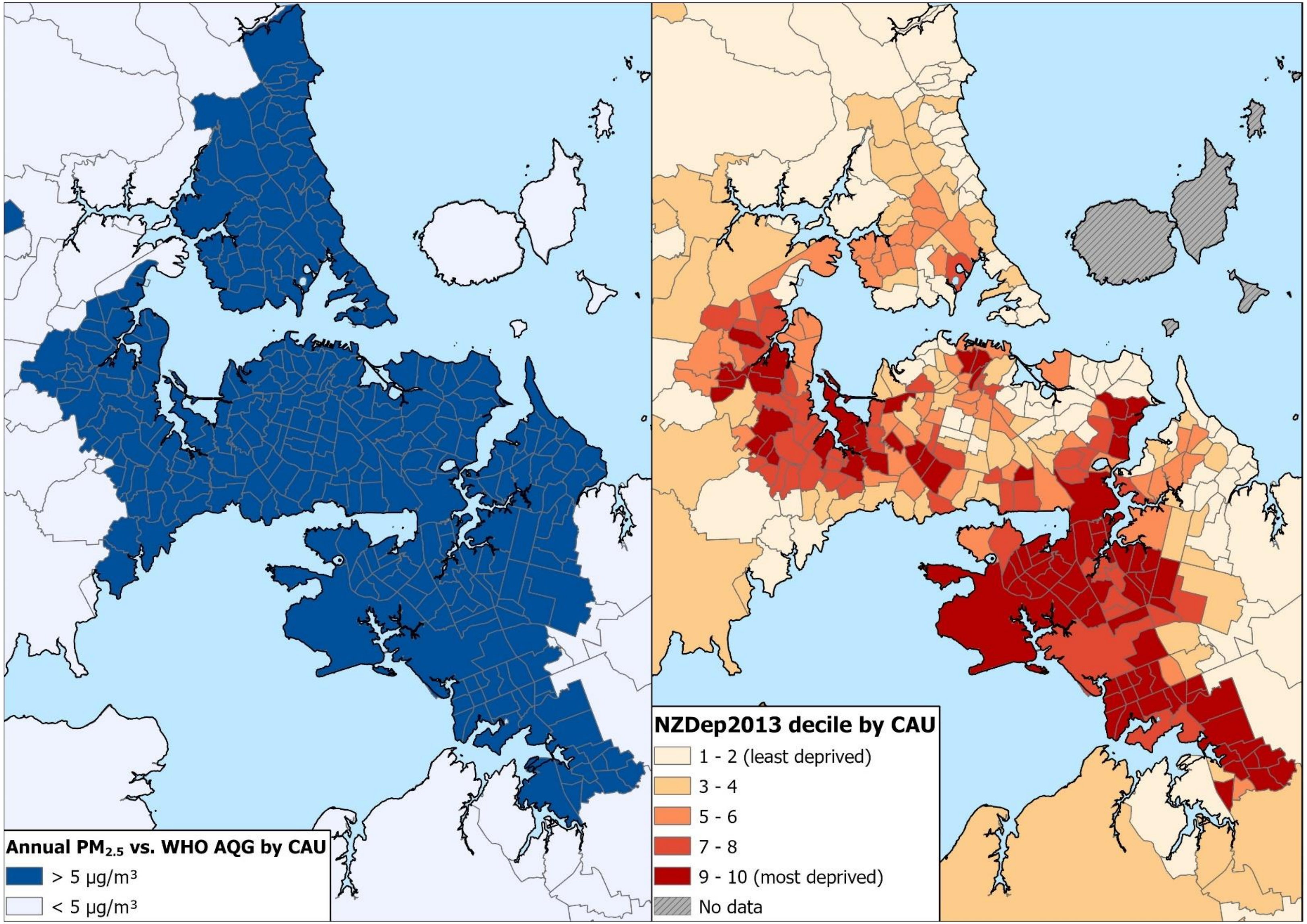


FIGURE 17: Locations in Auckland that exceed the WHO AQG for annual $PM_{2.5}$ (left hand side) and NZDep2013 deciles (right hand side) for Auckland urban areas by census area unit



3.5 EXPOSURE AND ETHNICITY

We explored the relationship between ethnic groups and chronic exposure to air pollution in New Zealand.

Table 2 presents national population-weighted annual average concentrations of NO_2 and $PM_{2.5}$ (for the year 2016) classified by ethnic group (2013, modified total response) in each census area unit. This shows:

- National population-weighted annual average concentrations of NO_2 are substantially higher for Asian, Pacific and Middle Eastern / Latin American / African (MELAA) ethnic groups compared with European Only exposure.
- National population-weighted annual average concentrations of NO_2 are similar for Māori and European Only.
- Population-weighted annual average concentrations of $PM_{2.5}$ are similar for all ethnic groups.

TABLE 2: National population-weighted annual average concentration of NO_2 and $PM_{2.5}$ for each ethnic group

Ethnic group (modified total response)[1]	Population-weighted annual average concentration (µg/m^3, 2016)	
	NO_2	$PM_{2.5}$
Total population	7.9	6.5
Māori	7.1	6.4
Pacific peoples	9.9	6.2
Asian	10.5	6.2
Middle Eastern / Latin American / African (MELAA)	9.9	6.4
Other	7.1	6.6
European Only*	7.3	6.7
WHO Air Quality Guideline (annual)	**10**	**5.0**

[1] 2013 census data. * The 'European Only' group only includes people who identify solely as European and is the comparator group; for all other ethnic groups, total response ethnic groups have been used (and therefore include everyone who identifies as that ethnic group, so these ethnic groups cannot be directly compared with each other).

Figure 18 shows the proportion of people in each ethnic group who are exposed to annual NO_2 concentrations below and above the WHO AQG of 10 µg/m^3. This graph shows that around half of Asian, Pacific peoples and MELAA ethnic groups (49-58% of each population) are exposed to annual NO_2 concentrations above the guideline.

Figure 19 presents the proportion of people in each ethnic group who are exposed to annual $PM_{2.5}$ concentrations below and above the WHO AQG of 5 µg/m^3. The proportion of people exposed to more than double the WHO AQG is also shown. Figure 19 shows that most New Zealanders (77–95% of the population) are exposed to annual $PM_{2.5}$ concentrations above the WHO guideline. However, there are differences in ethnic group exposure, with almost all (93-95%) of the Asian, Pacific peoples and MELAA ethnic groups exposed to $PM_{2.5}$ above the WHO guideline compared with 78% European Only.

FIGURE 18: Percent of population (y-axis) in each ethnic group (x-axis) who are exposed to annual NO_2 concentrations below and above the WHO AQG of 10 µg/m^3. Ethnic data are 2013 [StatsNZ], exposure data are 2016 [Kuschel et al., 2022].

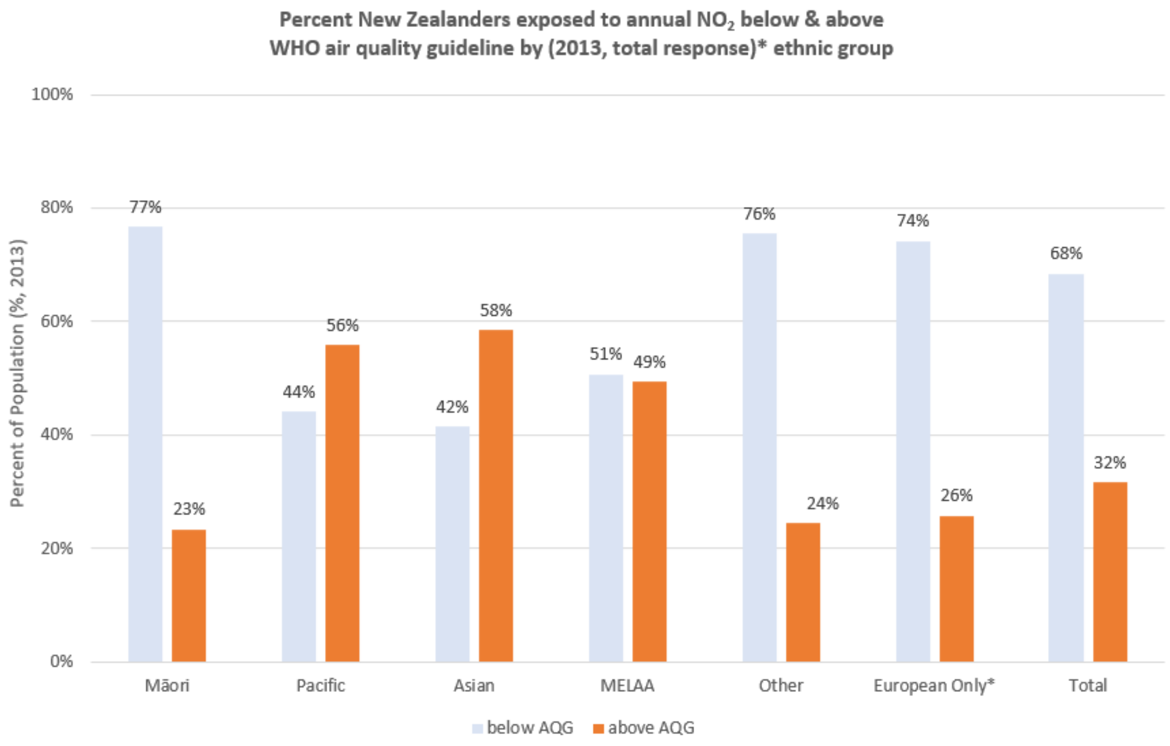
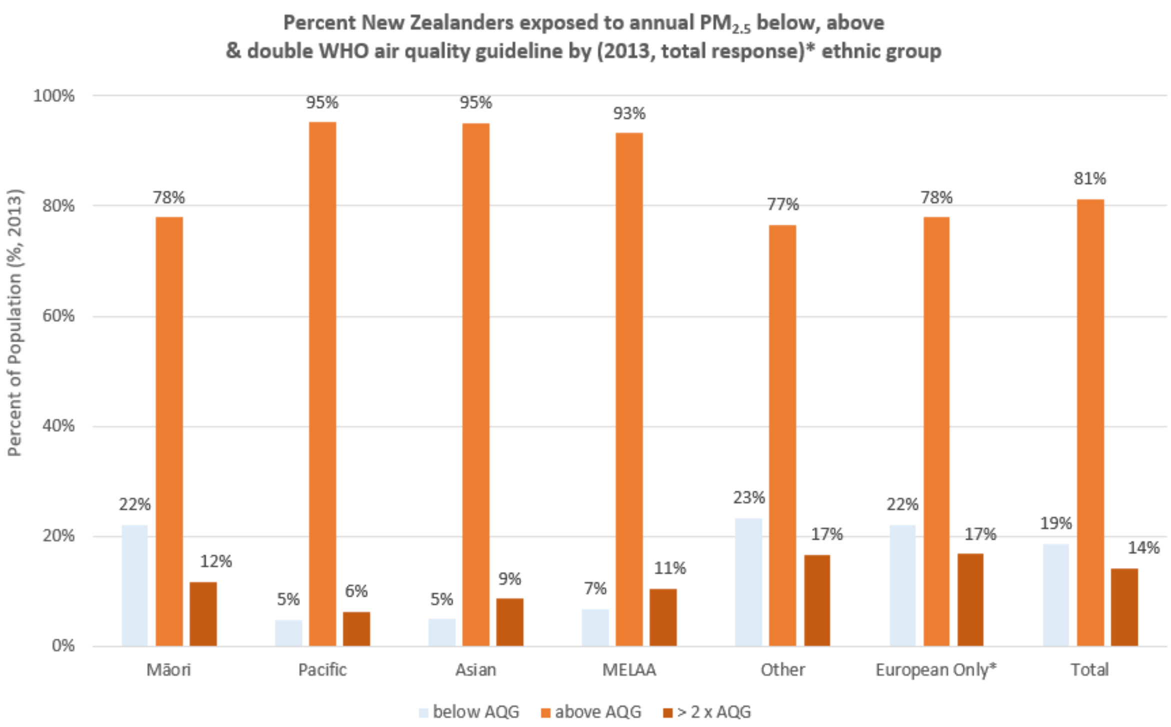


FIGURE 19: Percent of population (y-axis) in each ethnic group (x-axis) who are exposed to annual $PM_{2.5}$ levels below, above, and more than double the WHO AQG of 5 µg/m^3. Ethnic data are 2013 [StatsNZ], exposure data are 2016 [Kuschel et al., 2022].



*The 'European Only' group only includes people who identify solely as European; for all other ethnic groups, total response ethnic groups have been used (and therefore include everyone who identifies as that ethnic group, so these ethnic groups cannot be directly compared with each other).

3.6 URBAN NO_2 EXPOSURE AND ETHNICITY

Table 3 presents the population-weighted annual average exposure to NO_2 (for the year 2016) of different ethnic groups (2013, modified total response) for national and urban only populations in New Zealand.

Table 4 presents the population-weighted annual average exposure to NO_2 (for the year 2016) of different ethnic groups (2013, modified total response) for:

- Whangārei (Airshed);
- Auckland (Urban Airshed);
- Hamilton (City Airshed);
- Tauranga (City);
- Wellington (Airsheds);[8]
- Christchurch (Airshed);
- Dunedin (Airshed); and
- Invercargill (Airshed) populations.

TABLE 3: Population-weighted average exposure to annual NO_2 (2016) for each ethnic group in New Zealand (2013, modified total response) compared with urban areas in New Zealand

Ethnic Group (modified total response) [a]	Population-weighted annual average concentration NO_2 (µg/m³, 2016)	
	National	National Urban [b]
Total population	7.9	8.6
Māori	7.1	7.8
Pacific	9.9	10.1
Asian	10.5	10.7
MELAA	9.9	10.2
Other	7.1	8.1
European Only	7.3	8.2
WHO AQG = 10 µg/m³		

Notes: [a] Total response ethnic groups have been used (so each ethnic group includes everyone who identifies as that ethnic group), with the exception of 'European Only', which is the comparator group and only includes people who identify solely as European. [b] Urban areas are defined as main, secondary or minor urban areas as detailed in Kuschel et al., 2022. These include many smaller urban areas in New Zealand (e.g., from Kerikeri to Gore).

Table 3 shows a significant disparity in national population-weighted annual average exposure to NO_2 of different ethnic groups. For example, Table 3 shows that at the national level, only Asian people have a population-weighted annual average exposure to NO_2 (10.5 µg/m³) that exceeds the WHO guideline with other ethnic groups exposure being lower than the WHO guideline.

[8] Karori, Lower Hutt, Porirua, Wainuiomata, Wellington City & Upper Hutt Airsheds.

TABLE 4: Population-weighted annual average exposure to NO_2 (2016) for each ethnic group in New Zealand (2013, modified total response) compared with urban areas [b] of select New Zealand cities

Ethnic Group (modified total response) [a]	Population-weighted annual average concentration NO_2 (µg/m³, 2016)							
	Whangārei	Auckland	Hamilton	Tauranga	Wellington	Christchurch	Dunedin	Invercargill
Total population	6.4	11.2	9.2	7.1	6.7	12.4	9.8	7.6
Māori	6.4	11.1	9.2	7.1	6.1	12.6	9.8	7.4
Pacific	6.6	11.7	9.2	7.3	5.9	12.8	9.9	7.3
Asian	7.0	11.9	9.1	7.6	7.5	13.2	11.3	8.4
MELAA	6.9	11.8	9.2	7.5	7.4	13.1	10.9	8.4
Other	6.4	10.8	9.1	7.1	6.7	12.4	9.4	7.6
European Only	6.4	10.7	9.1	7.1	6.7	12.3	9.6	7.6
WHO AQG = 10 µg/m³								

Notes: [a] Total response ethnic groups have been used (so each ethnic group includes everyone who identifies as that ethnic group), with the exception of 'European Only', which is the comparator group and only includes people who identify solely as European. [b] Urban areas are defined as main, secondary or minor urban areas as detailed in Kuschel et al., 2022 in Whangārei Airshed, Auckland Urban Airshed, Hamilton City Airshed, Tauranga City (Council district), Wellington Airsheds, Christchurch Airshed, Dunedin Airshed and Invercargill Airshed.

However, Tables 3 and 4 also show higher population-weighted annual average exposure to NO_2 in urban areas (and particularly in the Auckland urban area) for *all* ethnic groups. It is also pertinent that almost all Pacific peoples, Asian and MELAA ethnic groups (> 95%) live in urban areas of New Zealand, with more than half living in the Auckland urban area (as shown in Appendix B). This suggests that the disparity in exposure for different ethnic groups is strongly influenced by the majority of these ethnic groups living in urban areas, in particular Auckland. In contrast, the proportion of Māori living in urban areas of New Zealand is around 84%, with only 21% living in the Auckland urban area (as shown in Appendix B).

Further to this, it is notable how much higher the population-weighted annual average exposure to NO_2 is for urban Aucklanders (11.2 $\mu g/m^3$) and Christchurch residents (12.4 $\mu g/m^3$) compared with the national average for urban New Zealanders (8.6 $\mu g/m^3$). Urban areas are defined as main, secondary or minor urban areas as detailed in Kuschel et al., 2022 and include many smaller urban areas in New Zealand (e.g., from Kerikeri to Gore). These smaller urban areas have significantly lower annual NO_2 than Auckland and Christchurch.

Table 4 shows that some ethnic disparities exist in these cities. Asian people and MELAA ethnic groups (and to a lesser extent, Pacific peoples and Māori) have higher population-weighted annual average exposure to NO_2 relative to European Only in some of these cities. For example:

- In urban Auckland, Asian (11.9 $\mu g/m^3$), MELAA (11.8 $\mu g/m^3$), Pacific peoples (11.7 $\mu g/m^3$) and Māori (11.1 $\mu g/m^3$) have higher population-weighted annual average exposure to NO_2 than European Only (10.7 $\mu g/m^3$). In urban Auckland, all ethnic groups had a population-weighted annual average exposure to NO_2 that exceeded the WHO guideline (10 $\mu g/m^3$).

- Christchurch has the highest population-weighted annual average exposure to NO_2 in the country, with all ethnic groups' population-weighted annual average exposure to NO_2 exceeding the WHO guideline for NO_2. Population-weighted annual average exposure to NO_2 were higher for all ethnic groups (Asian, MELAA, Pacific peoples and Māori) compared with the European Only group.

- Dunedin shows the highest disparity between ethnic groups, with Asian (11.3 $\mu g/m^3$) and MELAA (10.9 $\mu g/m^3$) ethnic groups' population-weighted annual average exposure to NO_2 exceeding the WHO guideline, and other ethnic groups' exposure being lower than the WHO AQG. Pacific peoples (9.9 $\mu g/m^3$) and Māori (9.8 $\mu g/m^3$) had slightly higher population-weighted annual average exposure than the European Only group (9.6 $\mu g/m^3$) in Dunedin.

The notable exception to this is Hamilton where there are no substantial disparities between any ethnic groups' exposure.

4. PRELIMINARY RESULTS: HEALTH IMPACTS

This section explores whether health impacts associated with air pollution vary in New Zealand by socioeconomic deprivation.

4.1 BASE HEALTH INCIDENCE DATA

Figure 21 shows base health incidence (case) rates for the New Zealand population stratified by NZDep2013 deciles for the key health outcomes assessed in the HAPINZ 3.0 model. This shows:

- Mortality (adults 30+ years, all non-external causes) per 100,000 adults (30+ years)
- Cardiovascular and respiratory hospital admissions (all ages) per 100,000 persons (all ages)
- Asthma prevalence (0-18 years) per child (0-18 years).

Figure 20: Rate of health cases per 100,000 persons (y-axes) by NZDep2013 deciles (x-axis). Rates are per 100,000 persons (all ages) for hospitalisations and per 100,000 children (0-18-year-olds) for asthma prevalence (right-hand y-axis) and per 100,000 adults (30+ years) for non-external cause mortality (left hand y-axis).

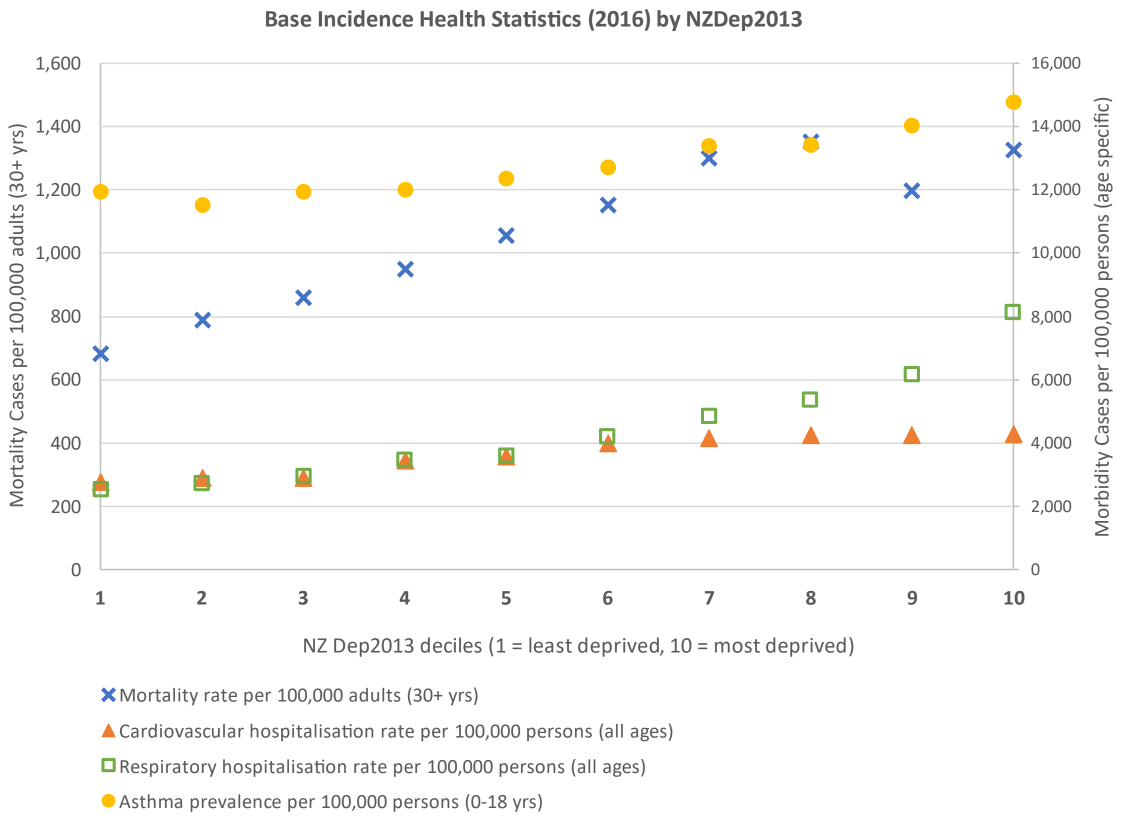


Figure 21 shows that the base health incidence[9] rates for these health outcomes are higher in more deprived areas. This means that air pollution health impacts will be worse in more deprived areas due to a combination of higher NO_2 concentration in these areas (as discussed in previous section) **and** the higher base health incidence rates.

4.2 HEALTH IMPACTS BY POLLUTANT

Table 5 presents estimated anthropogenic air pollution health impacts from the HAPINZ 3.0 model disaggregated by NZDep2013 deciles and by pollutant. Also shown in Table 5 is the ratio of case numbers in NZDep2013 decile 10 to those in NZDep2013 decile 1.

Table 5 shows for example, that the base incidence (case) rate of respiratory hospitalisations in decile 10 areas is 3.2 times higher than in decile 1 areas. However, Table 5 also shows that in the most deprived areas (decile 10) compared with the least deprived areas (decile 1) the:

- rate of premature mortality (30 years +) associated with exposure to NO_2 and $PM_{2.5}$ is **two times higher**
- rate of respiratory hospitalisation associated with exposure to NO_2 is **four times higher**
- rate of respiratory hospitalisation associated with exposure to $PM_{2.5}$ is **three times higher**
- rate of cardiovascular hospitalisation associated with exposure to NO_2 and $PM_{2.5}$ is **1.7 times higher**
- rate of asthma prevalence in 0-18-year-olds associated with exposure to NO_2 is **1.6 times higher**

The estimated rates of health impacts associated with air pollution by NZDep2013 decile are presented graphically in **Figure 22** for NO_2 and **Figure 23** for $PM_{2.5}$. It should be noted that the health impacts presented in Figures 18 and 19 are associated with exposure to NO_2 and $PM_{2.5}$ from anthropogenic (human-made) sources only and exclude natural sources.

Figure 22 illustrates how the underlying health inequities between different socioeconomic deprivation deciles shown in Figure 16, are exacerbated by higher NO_2 concentrations in higher decile areas.

Figure 23 shows that despite annual average $PM_{2.5}$ concentrations being very similar in all locations and all populations, more deprived populations have increased adverse health outcomes due to anthropogenic $PM_{2.5}$ exposure, because the base health incidence rates are higher.

Importantly, Table 5 also shows that in addition to air pollution increasing inequities in health impacts in lower socioeconomic deprivation areas, the overall burden (i.e., the actual number of people affected) is also higher in more deprived areas.

[9] Or higher prevalence with respect to asthma. *Prevalence* is the proportion of a population who *have* a specific characteristic in a given time period. *Incidence* is the number of new cases in a population at risk in a given time period.

TABLE 5: HAPINZ 3.0 base health incidence data* and estimated cases due to anthropogenic air pollution by NZDep2013 decile (rate per 100,000 people, for year 2016)

Health outcome	NZDep2013 decile										Ratio of NZDep2013 decile 10 / decile 1
	1	2	3	4	5	6	7	8	9	10	
Base health incidence cases (rate per 100,000)											
Mortality (30+ yrs)	682	790	861	951	1,056	1,152	1,299	1,351	1,197	1,326	1.9
Cardiovascular hospitalisation (all ages)	2,773	2,901	2,916	3,459	3,591	3,998	4,158	4,248	4,251	4,298	1.6
Respiratory hospitalisation (all ages)	2,547	2,733	2,944	3,476	3,587	4,208	4,854	5,378	6,179	8,136	3.2
Asthma prevalence (0-18 yrs)	11,941	11,519	11,938	12,012	12,367	12,724	13,398	13,408	14,036	14,770	1.2
Cases due to NO_2 (rate per 100,000)											
Mortality (30+ yrs)	42	55	62	65	69	71	93	97	82	91	2.2
Cardiovascular hospitalisation (all ages)	28	32	34	40	38	41	50	51	52	52	1.9
Respiratory hospitalisation (all ages)	66	80	88	104	101	118	156	172	203	271	4.1
Asthma prevalence (0-18 yrs)	879	982	1,006	1,019	1,006	1,019	1,216	1,206	1,301	1,415	1.6
Cases due to $PM_{2.5}$ (rate per 100,000)											
Mortality (30+ yrs)	29	33	35	44	45	51	64	58	52	53	1.8
Cardiovascular hospitalisation (all ages)	41	42	40	52	53	62	70	66	67	63	1.5
Respiratory hospitalisation (all ages)	24	24	25	33	32	40	50	51	60	74	3.1
Cases due to NO_2 and $PM_{2.5}$ (rate per 100,000)											
Mortality (30+ yrs)	71	88	97	109	114	122	157	155	134	144	2.0
Cardiovascular hospitalisation (all ages)	69	75	74	92	91	102	120	116	119	115	1.7
Respiratory hospitalisation (all ages)	90	104	113	137	133	158	206	223	264	345	3.9

* The mortality and hospitalisation rates per 100,000 people were calculated from HAPINZ 3.0 cases (total) data, which is the total number of health cases (premature deaths, hospital admissions) in the area of interest (i.e., health incidence data based on analysis of Ministry of Health mortality and hospitalisations datasets by census area unit). The asthma prevalence rate per 100,000 people was calculated based on asthma prevalence estimates included in HAPINZ 3.0 by census area unit.

Figure 21: Estimated health impacts associated with exposure to anthropogenic NO_2 per 100,000 people (y-axes) by NZDep2013 deciles (x-axis). Rates are per 100,000 persons (all ages) for hospitalisations and per 100,000 adults (30+ years) for non-external cause mortality (left hand y-axis), and per 100,000 children (0-18-year-olds) for asthma prevalence (right-hand y-axis).

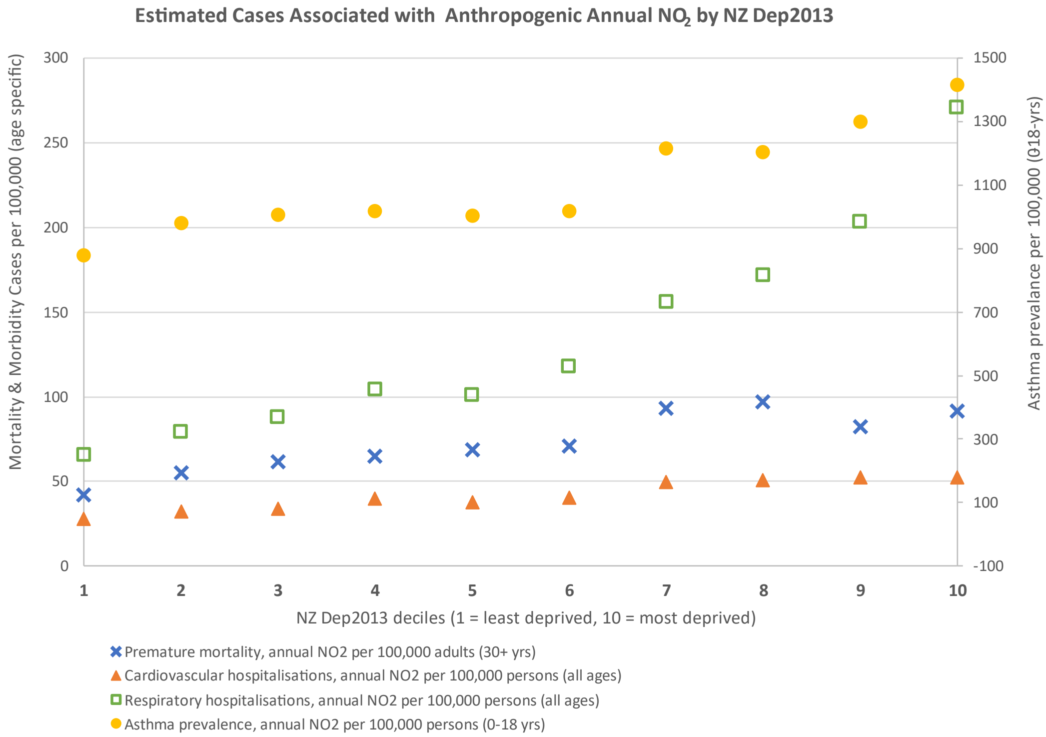
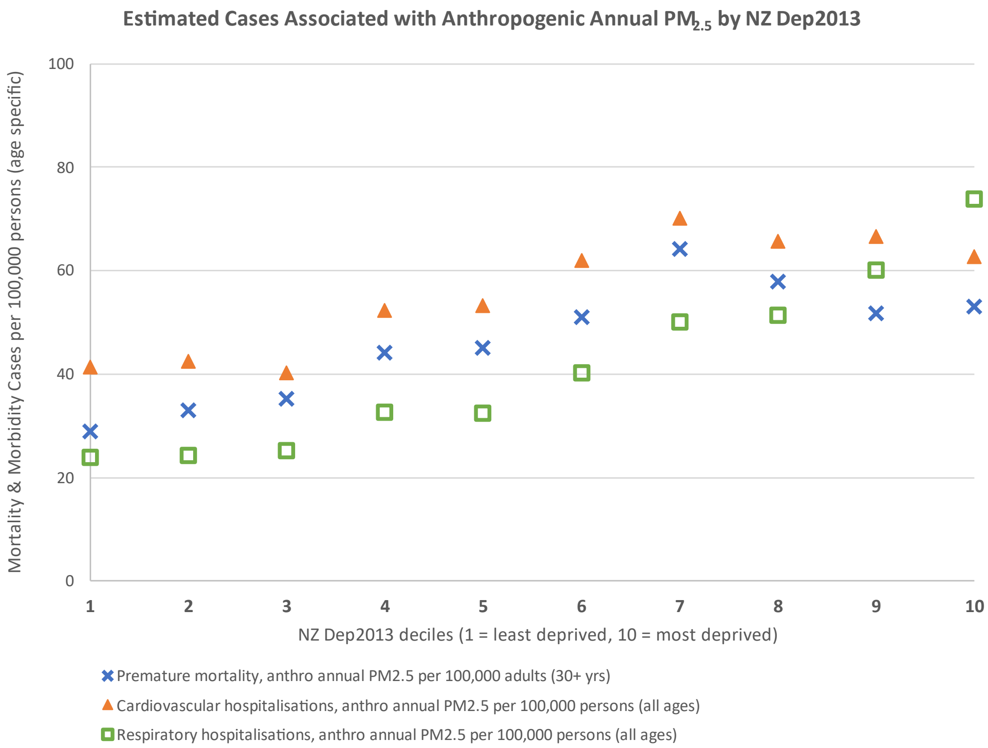


Figure 22: Estimated health impacts associated with exposure to anthropogenic $PM_{2.5}$ per 100,000 people (y-axis) by NZDep2013 deciles (x-axis). Rates are per 100,000 persons (all ages) for hospitalisations and per 100,000 adults (30+ years) for non-external cause mortality.



5. DISCUSSION

Exposure to nitrogen dioxide (NO_2)

Whilst most New Zealanders (~70%) breathe air that is below the WHO Air Quality Guidelines (AQG) for nitrogen dioxide, exposure to NO_2 is higher, on average, in areas with higher levels of socioeconomic deprivation. We found that, on average, people living in the most deprived areas (NZDep2013 decile 10) of Aotearoa are exposed to significantly higher chronic levels of NO_2 than people living in the least deprived areas (NZDep2013 decile 1).

Of note, the Counties Manukau District Health Board area is disproportionately impacted by both elevated exposure to annual NO_2 and a higher proportion of the population living in the most deprived areas (refer Figure 12). The inequity in chronic exposure to NO_2 between Counties Manukau and other district health boards is notable at the national level; the 124,000 people in Counties Manukau NZDep2013 decile 10 areas who are exposed to annual levels of NO_2 above the WHO guideline represent nearly one third (31%) of New Zealand's entire NZDep2013 decile 10 population.

We found that some ethnic groups – namely Asian, Pacific peoples and Middle Eastern/Latin American/African (MELAA) ethnic groups – were more likely to be exposed to long-term NO_2 levels above WHO guideline levels compared with European Only. We explored whether this disparity might be due to the majority of some ethnic groups living in urban areas, in particular Auckland. It does appear to be the case that there is a rural/urban split.

However, some disparities remain in some New Zealand cities, in particular with Asian people and MELAA ethnic groups (and to a lesser extent, Pacific peoples and Māori) typically having higher population-weighted annual average exposure to NO_2 than European Only in some New Zealand cities (for example, Auckland, Christchurch and Dunedin).

Exposure to $PM_{2.5}$

The picture is quite different for chronic exposure to $PM_{2.5}$, with most New Zealanders (~80%) breathing air that is above the WHO AQG for $PM_{2.5}$. Population-weighted annual average concentrations of $PM_{2.5}$ are similar for all ethnic groups.

For socioeconomic deprivation, on average the population-weighted annual average exposure to $PM_{2.5}$ is similar across NZDep2013 deciles when looking at the national-level data. However, these patterns differ somewhat by district health board. The primary source of $PM_{2.5}$ in Aotearoa New Zealand is domestic solid fuel combustion for home heating.

Health impacts of NO_2 and $PM_{2.5}$

We found that the burden of health impacts from air pollution (both NO_2 and $PM_{2.5}$) is much higher in more deprived areas in both relative and absolute terms. This can be explained by two factors:

(i) underlying structural inequities, specifically higher base health incidence rates of all health outcomes studied (mortality, respiratory & cardiovascular hospitalisations, childhood asthma prevalence) in more deprived areas; as well as

(ii) higher levels of exposure to air pollution in more deprived areas, and thus a higher proportion of health impacts due to air pollution.

This means that air pollution health impacts will be worse in more deprived areas due to a combination of higher pollutant concentration in these areas **and** the higher base health incidence rates.

Overall, the data shows that people in more deprived areas are affected more strongly by air pollution. This means that policy that targets air pollution improvements in more deprived areas would deliver bigger health benefits, especially policy to reduce motor vehicle emissions (the main source of NO_2).

It is important to note that we have made no adjustments for age, gender, ethnicity or smoking in this preliminary analysis of health impacts.[10] This means that the findings may alter if more comprehensive analyses are carried out.

[10] The exposure response functions used to estimate health impacts do address confounding factors including age, sex, ethnicity, income, education, smoking status and ambient temperature, in a New Zealand context (Hales et al., 2021).

REFERENCES

Atkinson J., Salmond C., Crampton P., 2014. *NZDep2013 Index of Deprivation.* Department of Public Health. University of Otago. Wellington. Division of Health Sciences. University of Otago. Dunedin. [Online: https://www.otago.ac.nz/wellington/otago069936.pdf]

Auckland Council, 2018. *About the Auckland Plan 2050*. Auckland. June. [Online: https://www.aucklandcouncil.govt.nz/plans-projects-policies-reports-bylaws/our-plans-strategies/auckland-plan/about-the-auckland-plan/Pages/aucklands-asian-population.aspx]

Curtis E., Paine S-J., Jiang Y., Jones P., Tomash I., Raumati I., Healey O., Reid P., 2020. Examining emergency departure inequities: Descriptive analysis of national data (2006-2012). *Emergency Medicine Australia.* 32(6):953-959. DOI: 10.1111/1742-6723.13592

Environmental Health Intelligence New Zealand (EHINZ). *Ethnic Profile (Regional Differences in Ethnic Groups)*. [Online: https://www.ehinz.ac.nz/indicators/population-vulnerability/ethnic-profile/#regional-differences-in-ethnic-groups] Accessed 22 May 2023.

Hales S., Atkinson J., Metcalfe J., Kuschel G. and Woodward A., 2021. Long term exposure to air pollution mortality and morbidity in New Zealand: Cohort study. *Sci Tot Env.* Vol 801. 20 Dec. 149660. doi.org/10.1016/j.scitotenv.2021.149660

Kuschel G. *et al.*, 2022. *Health and Air Pollution in New Zealand 2016 (HAPINZ 3.0).* Report prepared for Ministry for the Environment, Ministry of Health, Te Manatū Waka Ministry of Transport and Waka Kotahi NZ Transport Agency. Auckland. March. [Online] Available at www.environment.govt.nz

Loring B., Paine S-J., Robson B., Reid P. 2022. Analysis of deprivation distribution in New Zealand by ethnicity, 1991-2013. NZMJ. Nov 11;135(1565).

Ministry of Health, 2022. *Health and Independence Report 2021.* The Director-General of Health's annual report on the state of public health. 2021. Wellington. [Online: https://www.health.govt.nz/system/files/documents/publications/health-and-independence-report-2021-nov22.pdf]

Prüss-Üstün A *et al.,* 2003. *Introduction and methods: assessing the environmental burden of disease at national and local levels.* Geneva: World Health Organization. (WHO Environmental Burden of Disease Series, No. 1). https://apps.who.int/iris/handle/10665/42750

Research Data Alliance International Indigenous Data Sovereignty Interest Group. 2019. *CARE principles for Indigenous data governance*. The Global Indigenous Data Alliance. https://www.gida-global.org.

Sridhar S. et al., 2022. Health and Air Pollution in New Zealand 2016 (HAPINZ 3.0). He rangi hauora he iwi ora. Health effects model – Users' Guide. Prepared for Ministry for the Environment, Ministry of Health, Te Manatū

Stats NZ, 2020. *Population density and diversity in New Zealand*. 21 April 2020. [Online: https://www.stats.govt.nz/news/health-impacts-of-exposure-to-human-made-air-pollution/]

Stats NZ, 2023. *Health impacts of exposure to human-made air pollution*. 23 February 2023. [Online: https://storymaps.arcgis.com/stories/28ff84c3ff6640ee9f216580faa96dcc]

Walsh M. and Grey C., 2019. The contribution of avoidable mortality to the life expectancy gap in Māori and Pacific populations in New Zealand – a decomposition analysis. *NZMJ.* Vol 132. No. 1492: 29 Mar 2019. [Online: https://journal.nzma.org.nz/journal-articles/the-contribution-of-avoidable-mortality-to-the-life-expectancy-gap-in-maori-and-pacific-populations-in-new-zealand-a-decomposition-analysis]

WHO, 2021. *WHO air quality guidelines. Particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide*. Geneva: World Health Organization, 2021. [Online: https://www.who.int/]

Yao E., et al., 2022. Effects of Ethnic Classification on Substantive Findings in Adolescent Mental Health Outcomes. *J Youth & Adolescence*. **51**, pages 1581–1596 (2022). https://doi.org/10.1007/s10964-022-01612-6

APPENDIX A: NZDEP2013 BY DHB

Figure A1: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Aotearoa New Zealand

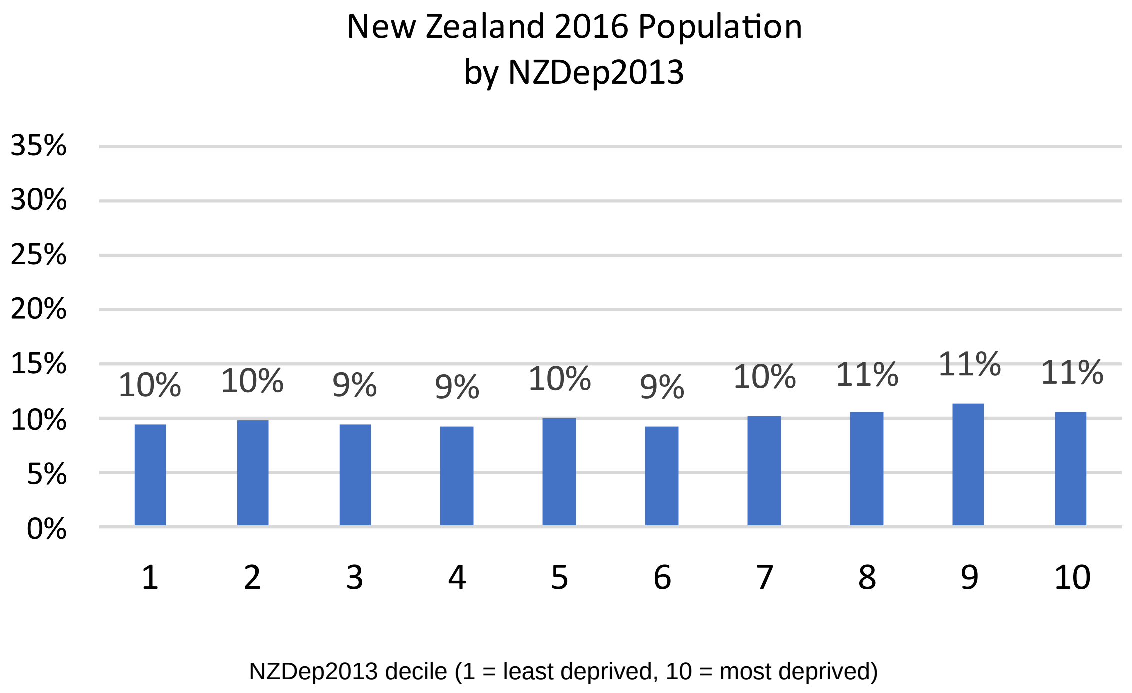


Figure A2: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Northland DHB

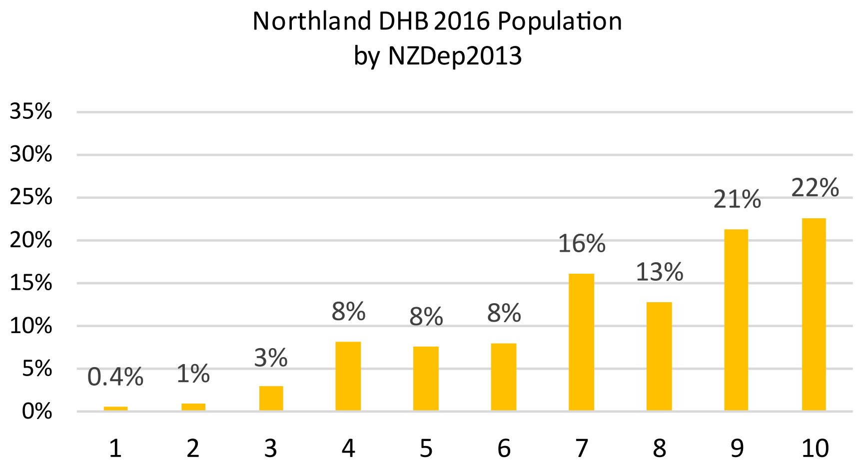


Figure A3: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Waitematā DHB

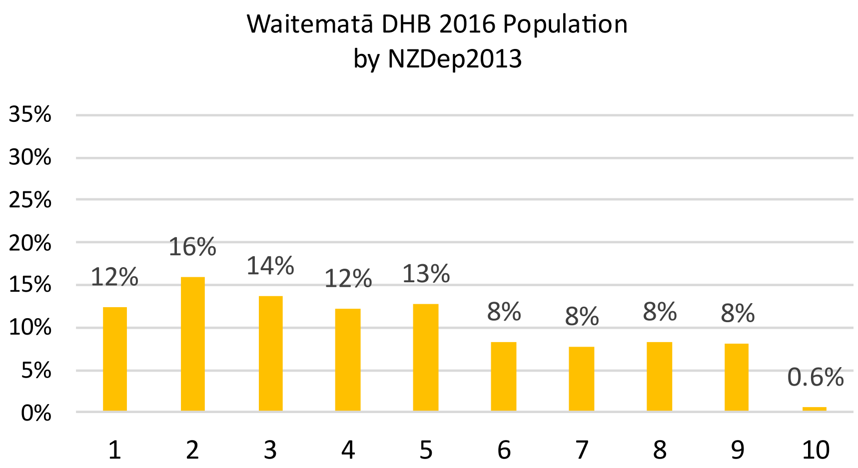
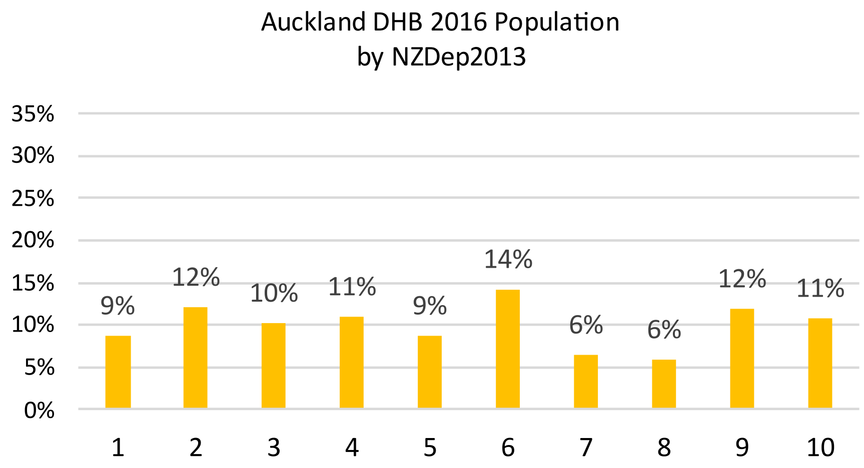


Figure A4: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Auckland DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A5: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Counties Manukau DHB

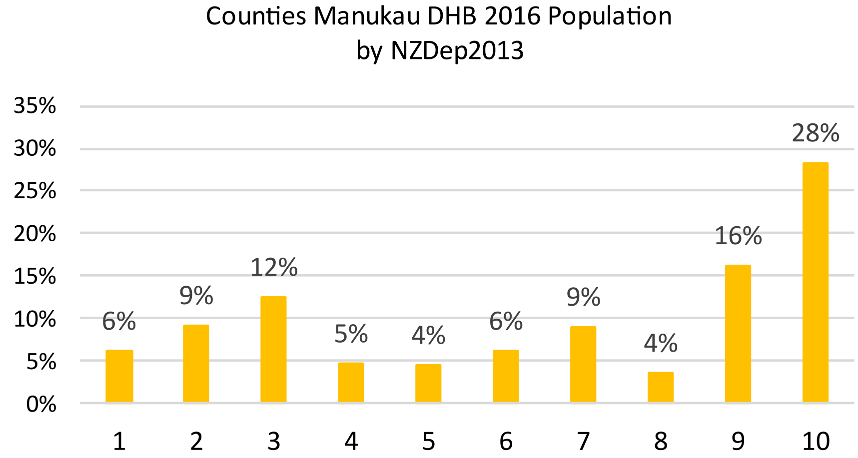


Figure A6: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Waikato DHB

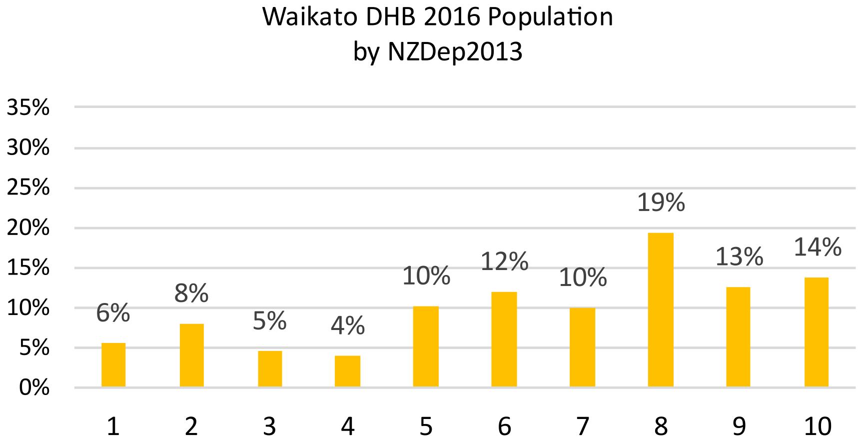
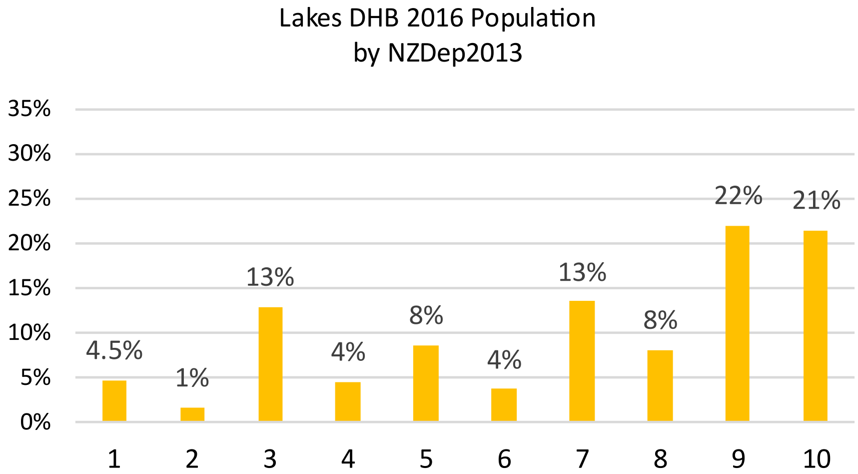


Figure A7: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Lakes DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A8: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Bay of Plenty DHB

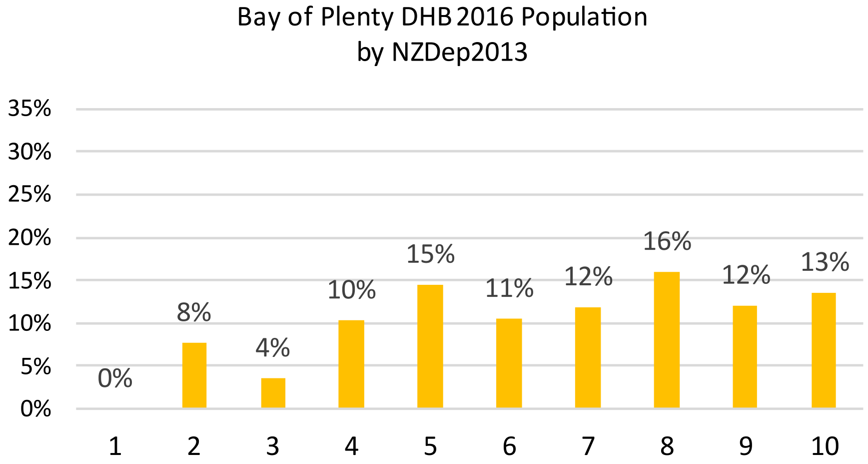


Figure A9: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Tairāwhiti DHB

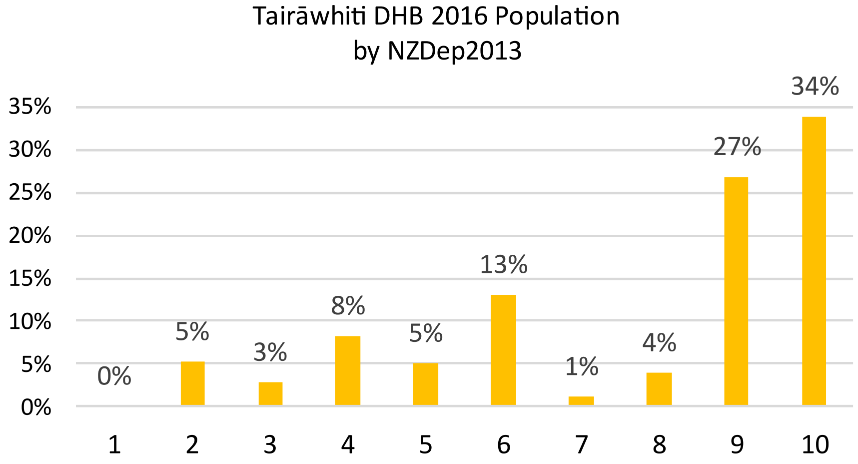
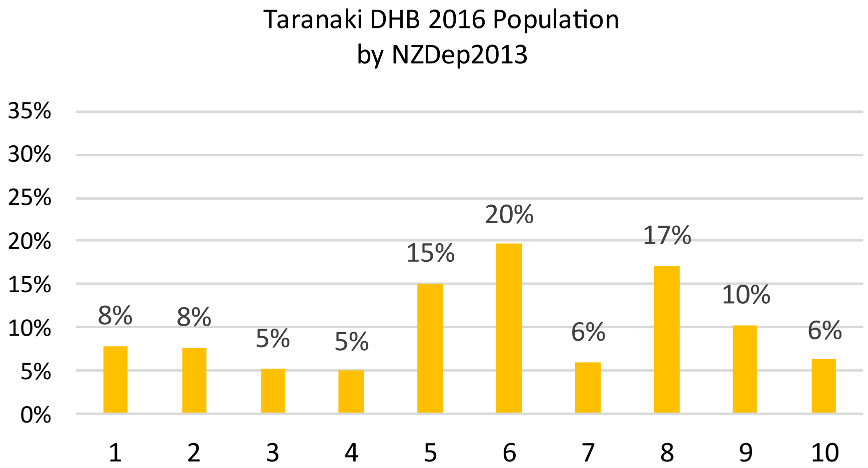


Figure A10: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Taranaki DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A11: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Hawke's Bay DHB

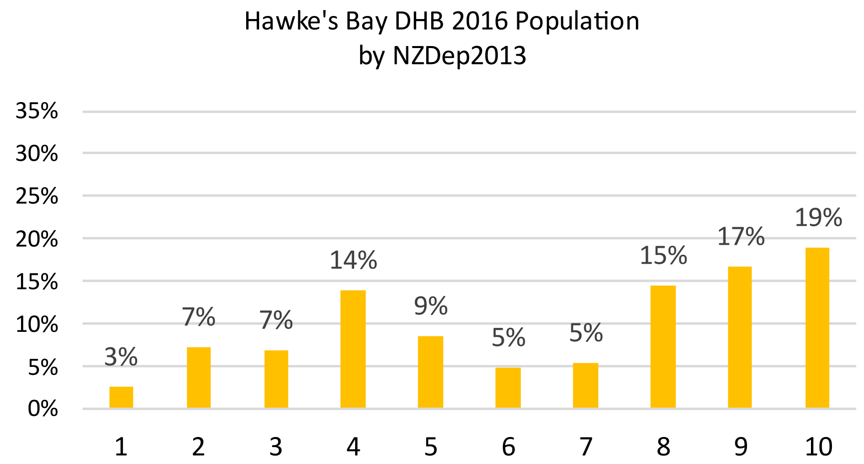


Figure A12: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Whanganui DHB

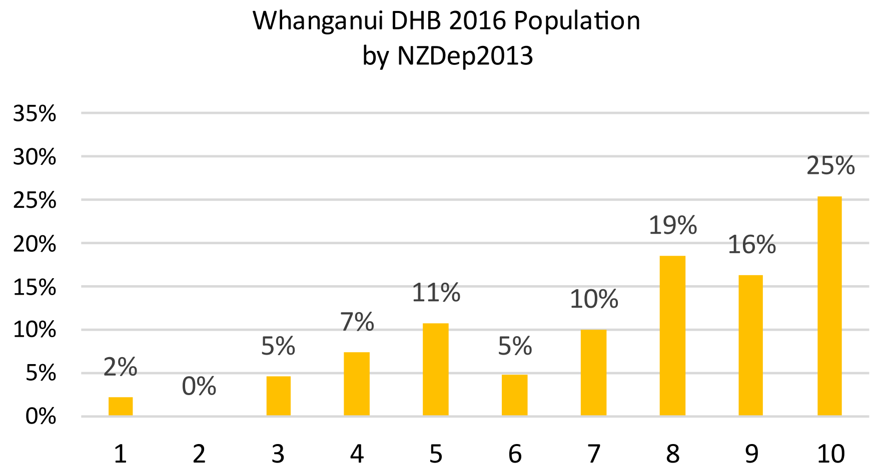
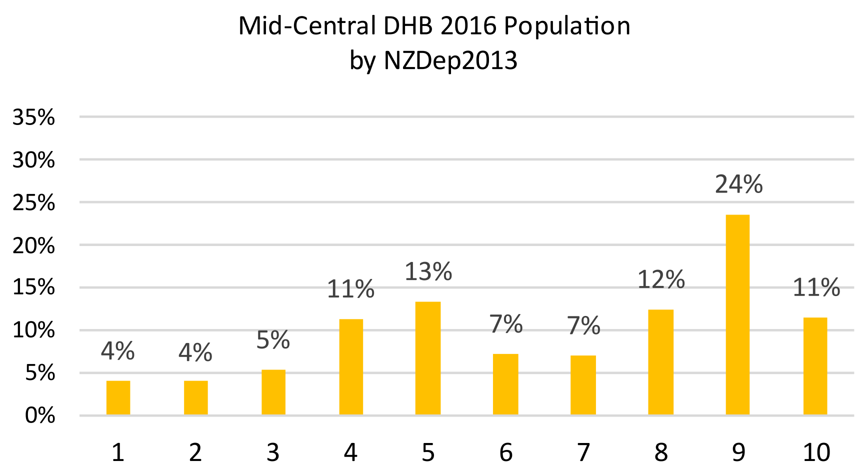


Figure A13: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Mid-Central DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A14: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Hutt Valley DHB

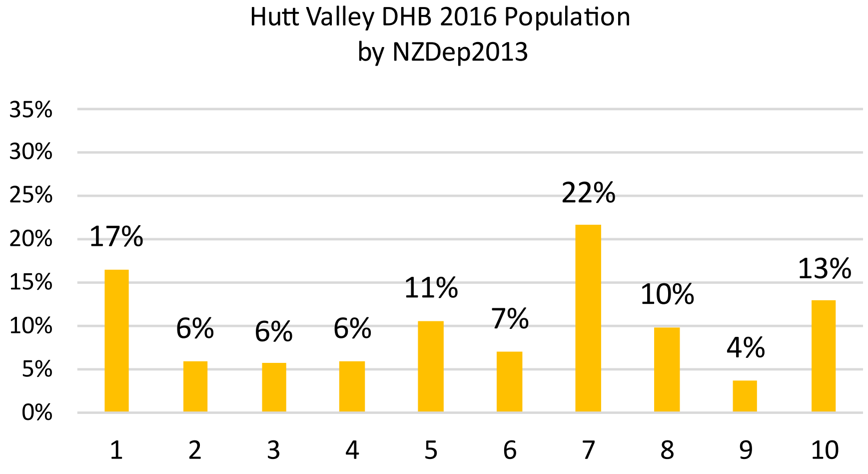


Figure A15: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Capital & Coast DHB

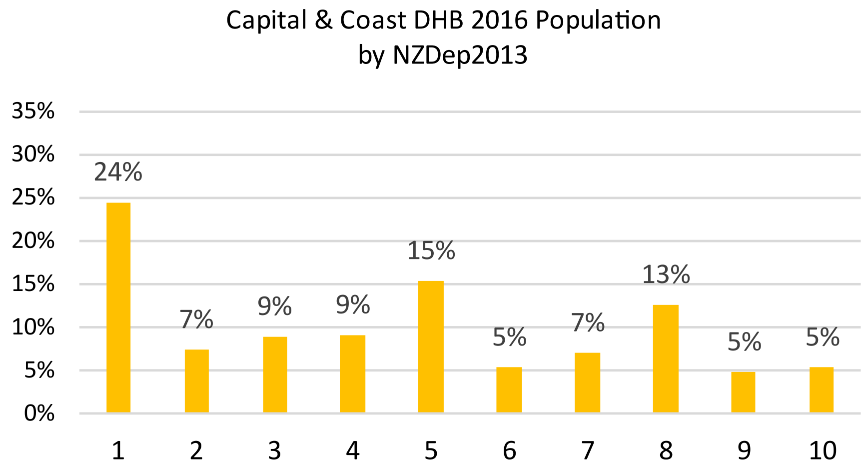
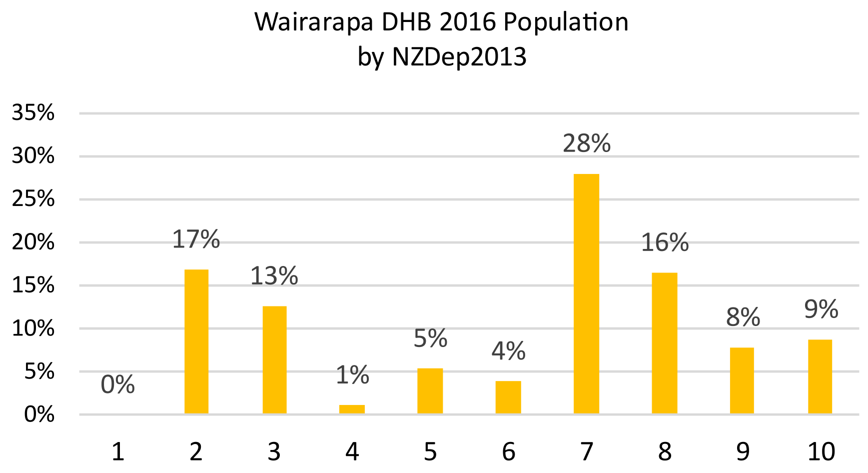


Figure A15: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Wairarapa DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A16: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Nelson Marlborough DHB

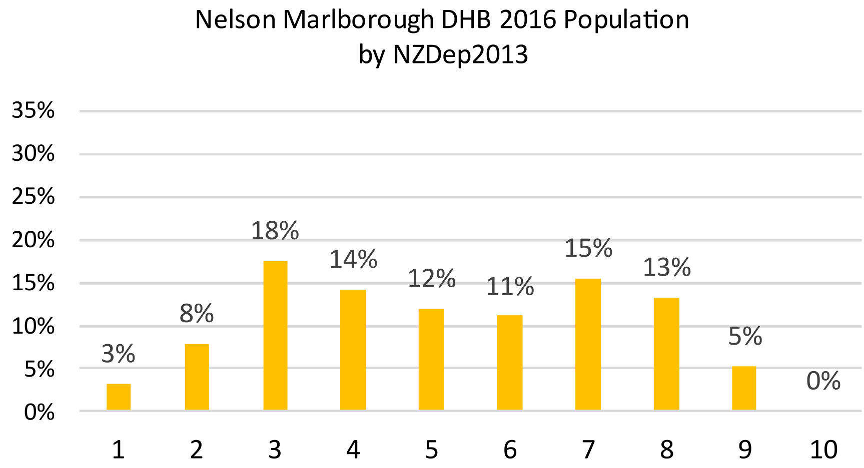


Figure A17: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): West Coast DHB

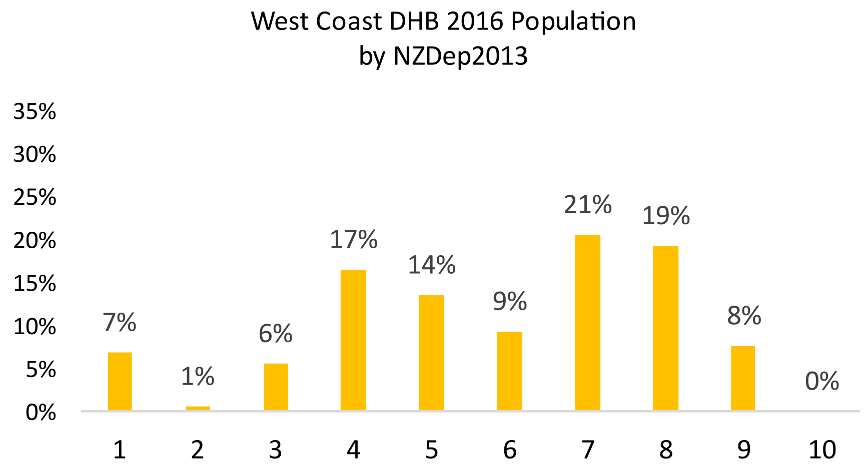
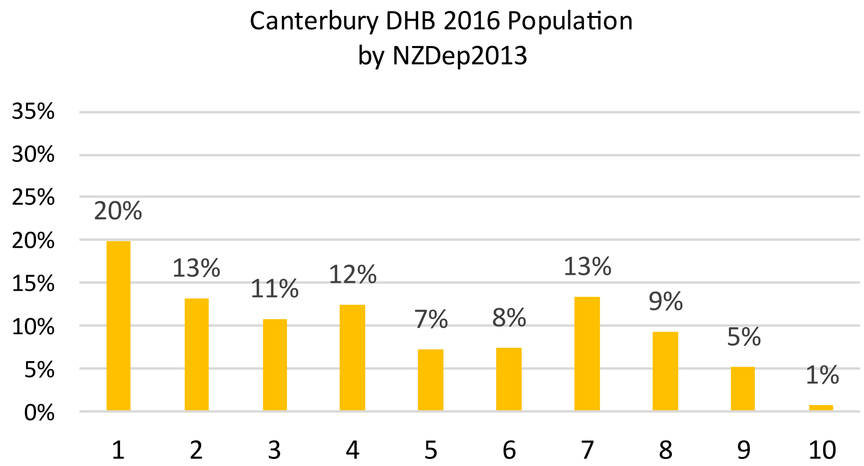


Figure A18: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Canterbury DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

Figure A19: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): South Canterbury DHB

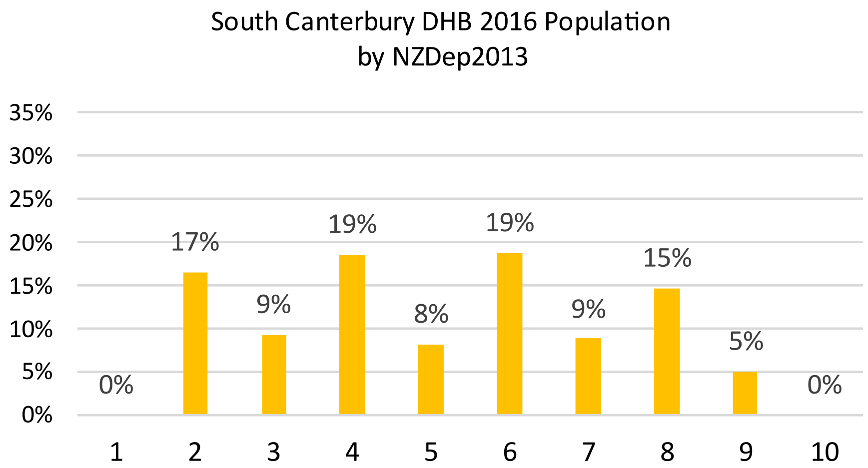
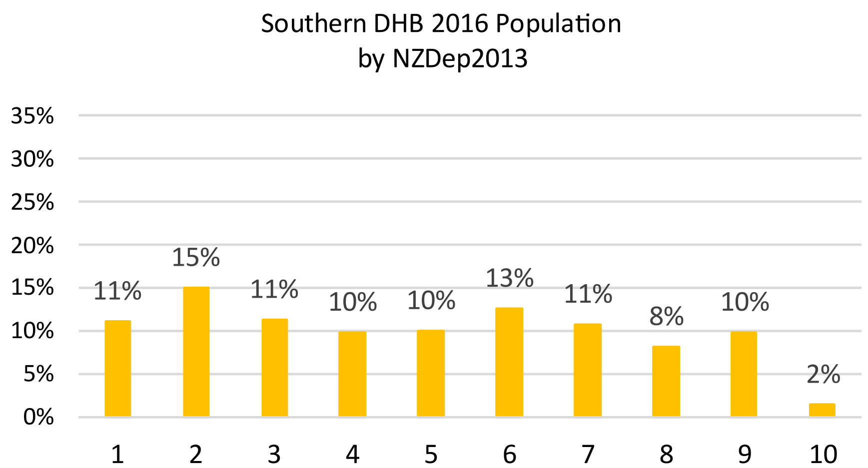


Figure A20: Percentage of 2016 population (y-axis) by NZDep2013 deciles (x-axis): Southern DHB



NZDep2013 decile (1 = least deprived, 10 = most deprived)

APPENDIX B: POPULATION BY ETHNIC GROUP AND URBAN AREA

Table 6: Population of each ethnic group in New Zealand (2013, modified total response)[a] in New Zealand urban[b] and urban areas of select New Zealand cities[c]. The percentage of the New Zealand total for each ethnic group is also shown for the urban areas.

Area	Ethnic Group (2013, modified total response) [a]											
	European Only		Māori		Pacific		Asian		MELLA		Other	
	Pop'n	%	Pop'n	%	Pop'n	%	Pop'n	%	Pop'n	%	Pop'n	%
New Zealand	2,604,081	-	598,578	-	295,908		471,744		46,980		67,734	
New Zealand urban	2,174,403	83%	504,999	84%	287,340	97%	460,332	98%	44,898	96%	55,401	82%
Whāngarei urban	24,447	1%	12,726	2%	1,491	1%	1,932	0%	219	0%	720	1%
Auckland Urban	566,571	22%	126,024	21%	189,924	64%	299,739	64%	24,204	52%	12,786	19%
Hamilton City urban	78,270	3%	28,593	5%	6,771	2%	18,417	4%	2,625	6%	2,184	3%
Tauranga City urban	80,805	3%	18,687	3%	2,580	1%	6,102	1%	741	2%	1,923	3%
Wellington airsheds urban	189,390	7%	41,283	7%	31,683	11%	34,797	7%	5,457	12%	5,046	7%
Christchurch urban	241,458	9%	26,934	4%	10,026	3%	30,555	6%	3,363	7%	6,054	9%
Dunedin urban	70,929	3%	7,170	1%	2,616	1%	6,756	1%	1,065	2%	1,986	3%
Invercargill urban	31,194	1%	6,072	1%	1,416	0%	1,395	0%	117	0%	927	1%

Notes: [a] Total response ethnic groups have been used (so each ethnic group includes everyone who identifies as that ethnic group), with the exception of 'European Only', which is the comparator group and only includes people who identify solely as European. [b] Urban areas are defined as main, secondary or minor urban areas as detailed in Kuschel et al., 2022. [c] Urban areas in Whangārei Airshed, Auckland Urban Airshed, Hamilton City Airshed, Tauranga City (Council district), Wellington Airsheds, Christchurch Airshed, Dunedin Airshed and Invercargill Airshed.

Science for Communities

INSTITUTE OF ENVIRONMENTAL
SCIENCE AND RESEARCH LIMITED

Kenepuru Science Centre
34 Kenepuru Drive, Kenepuru, Porirua 5022
PO Box 50348, Porirua 5240
New Zealand
T: +64 4 914 0700 **F:** +64 4 914 0770

Mt Albert Science Centre
120 Mt Albert Road, Sandringham, Auckland 1025
Private Bag 92021, Auckland 1142
New Zealand
T: +64 9 815 3670 **F:** +64 9 849 6046

NCBID – Wallaceville
66 Ward Street, Wallaceville, Upper Hutt 5018
PO Box 40158, Upper Hutt 5140
New Zealand
T: +64 4 529 0600 **F:** +64 4 529 0601

Christchurch Science Centre
27 Creyke Road, Ilam, Christchurch 8041
PO Box 29181, Christchurch 8540
New Zealand
T: +64 3 351 6019 **F:** +64 3 351 0010

www.esr.cri.nz