The Impact of Air Pollution ($PM_{2.5}$) in Subnational Australian Life Expectancy

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Abstract

Australia is renowned for having some of the cleanest air globally, yet air pollution remains a persistent issue that significantly impacts life expectancy. This study aims to understand the primary causes of annual increases in ambient particulate matter ($PM_{2.5}$) in Australia and measure the number of life-years lost (LYL) due to $PM_{2.5}$, considering geographical and demographic differences from 1990 to 2020. Demographic data used in this study were obtained from the Australian Bureau of Statistics and the Australian Human Mortality Database, while annual levels of $PM_{2.5}$ concentrations were averaged from geophysical parameter analysis from Earthdata. The findings indicate that dust storms and bushfires were the main sources of $PM_{2.5}$ over the 30-year period. South Australia and the Northern Territory consistently exceeded both the national limit and the WHO guideline for $PM_{2.5}$ concentrations. Although there was no clear time trend in the impact of $PM_{2.5}$ on life expectancy, South Australia and the Northern Territory exhibited higher LYL compared to other regions, with a significant gender gap, as males had higher LYL than females in all regions and every year. Australian Capital Territory showed the lowest LYL due to $PM_{2.5}$ in years without major pollution events. LYL varied significantly between Greater Cities and Rest of State, with rural regions in Queensland, South Australia, Western Australia, and Tasmania having higher LYL. Only in Northern Territory, there was no significant difference in LYL between urban and rural areas. A wider gap between Greater Cities and Rest of State was found in South Australia. Additionally, elderly individuals had higher LYL than adults. These results highlight the need for targeted interventions to address air pollution and its health impacts across different regions and demographics in Australia.

1. Introduction

Air pollution has been a significant concern for populations worldwide for over a decade. The Sustainable Development Goals (SDGs) emphasise this issue, with specific targets aimed at reducing mortality from environmental factors (Target 3.9), minimising the environmental impacts in urban areas (Target 11.6), and managing pollution and waste to decrease the release of pollutants that affect the global environment and human health (Target 12.4) (United Nations, 2015, 2024). Outdoor air pollution is a major contributor to the global burden of disease and a key factor in the decline of life expectancy worldwide (Lelieveld et al., 2020; Somboonsin et al., 2023). Specifically, particulate matter less than 2.5 micrometres ($PM_{2.5}$), which arises from both man-made activities such as industry, transport, and agricultural burning, as well as natural events like dust storms and wildfires (Butler & Whelan, 2018; Hanigan et al., 2021; Pinichka et al., 2017), often exceeds the World Health Organization's standard limits in several countries (Baklanov et al., 2016).

$PM_{2.5}$ data can be accessed from several sources. Although ground station data is widely recognised as the most accurate and effective means of measurement (Palmer et al., 2018), it has limitations, particularly its inability to monitor all areas (Li et al., 2021; Zeydan & Wang, 2019). In recent years, the use of remote sensing techniques to assess $PM_{2.5}$ levels via satellite has grown, owing to their cost-effectiveness and capability to monitor regions beyond the reach of ground-based stations (Buchard et al., 2016; Chen et al., 2021; Chu et al., 2016). NASA satellites, for example, allow researchers to average $PM_{2.5}$ concentrations in specific areas of interest, such as national, sub-national, and sub-district levels (Chidburee et al., 2023). However, the use of this measurement method remains less common in pacific islands countries, including Australia.

Despite Australia being ranked among the top ten countries for good air quality (IQAir, 2023; Lim et al., 2020), the country experiences frequent bushfires during the summer months and dust storms due to its dry landscape, leading to elevated levels of $PM_{2.5}$ (Cao et al., 2023; Graham et al., 2021; Hill et al., 2021; Ryan et al., 2021). The impact of air pollution on the Australian population has received comparatively less attention than in other regions, such as Africa and Asia. Existing studies on the long-term effects of $PM_{2.5}$ on life expectancy, especially at the subnational level, are limited, even though no Australian cities have consistently achieved the National Environment Protection Measures (NEPM) standard for $PM_{2.5}$ (de Jesus et al., 2020; Hertzog et al., 2024). Additionally, there is a gap in Australian research focusing on how $PM_{2.5}$ affects different genders and age groups, with limited studies exploring these variations comprehensively. Existing research has typically focused on specific genders, geographic areas, age groups, and causes of death (Chen et al., 2016; Dirgawati et al., 2019; Yu et al., 2020). However, studies comparing the overall impact of $PM_{2.5}$ on all-cause mortality across subnational regions, and across different age and gender groups, are relatively scarce.

To quantify mortality attributable to $PM_{2.5}$, the World Health Organisation developed the AirQ+ software, designed to support global research in this area. AirQ+ enables users to assess both short- and long-term exposure to pollutants, including particulate matter, thereby facilitating the development of studies that inform policies and interventions (World Health Organization, 2020). This software has been widely used in numerous countries (Deindee & Al-Fatlawi, 2024; Hadei et al., 2020; Hermayurisca & Taneepanichskul, 2023; Kliengchuay et al., 2022; Naghan et al., 2022). However, no study has yet utilised AirQ+ to examine $PM_{2.5}$-related life expectancy in Australia.

To address these gaps, this study aims to employ AirQ+ software and satellite data to analyse deaths attributable to $PM_{2.5}$ across Australia, quantifying its impact on life expectancy from 1990 to 2020. By comparing $PM_{2.5}$ levels with major events that contribute to its increase, such as bushfires and dust storms, this study will also examine the effects of $PM_{2.5}$ on mortality, differentiated by sex, age, and geographic area, specifically within Greater Capital City Statistical Areas (GCCSAs). This comprehensive approach aims to highlight regional disparities and temporal trends, guiding targeted public health interventions and informing policy formulation.

2. Methodology

2.1 Data

This study utilised three primary data sources: the Australian Bureau of Statistics (ABS), the Australian Human Mortality Database (AHMD), and the Bridge Between Data and Science version 4.40, Giovanni). Demographic data, including age- and sex-specific deaths, population sizes, and mortality rates, were sourced from the AHMD for state-level analysis and from the ABS for GCCSAs (AHMD; Australian Bureau of Statistics, 2022, 2023). According to the ABS geographic classification, this study focuses on eight states and territories: New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA), Western Australia (WA), Tasmania (TAS), Northern Territory (NT), and the Australian Capital Territory (ACT). For GCCSAs, areas were divided into greater city and rest of state for each state and territory, except for the ACT, which is not subdivided. More detailed information about Australian geography is provided in the supplementary materials and elsewhere (Australian Bureau of Statistics, July 2021 - June 2026).

Data on air particulate matter ($PM_{2.5}$) concentrations were obtained from Giovanni (Geospatial Interactive Online Visualization and Analyse Infrastructure), the Bridge Between Data and Science version 4.40 (https://giovanni.gsfc.nasa.gov/giovanni/), specifically the Total Surface Mass Concentration – $PM_{2.5}$ dataset. Giovanni is an online platform provided by NASA that offers access to a vast array of Earth science data from various satellite missions and models. The $PM_{2.5}$ data from Giovanni were calculated with consideration of relative humidity, featuring a geometric diameter of less than 2.5 microns, derived from the Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2). This reanalysis project compiles historical climate data by integrating observations from satellites, ground-based instruments, and other sources, creating a comprehensive atmospheric dataset (Buchard et al., 2016; GES DISC).

2.2 Methods

(1) Deaths attributable to $PM_{2.5}$

The estimation of deaths due to $PM_{2.5}$ was conducted using AirQ+ version 2.2, a software tool from the World Health Organization (WHO) designed for health risk assessment of air pollution. AirQ+ facilitates the calculation of deaths attributed to air pollution in this study, requiring inputs such as death or incidence rates, population sizes aged 30 and over, and average annual pollutant concentration levels. More details on the software and its methodology are provided elsewhere (Amini et al., 2024; World Health Organization, 2020).

To obtain the $PM_{2.5}$ concentration levels, the Raster package in R statistical software was used. Shapefiles downloaded from Giovanni were overlaid with ABS boundaries from the Australian Statistical Geography Standard Edition 3 (Australian Bureau of Statistics, 2021) to ensure accurate geographic matching. The average $PM_{2.5}$ concentration levels were then computed for both state and territory and GCCSA levels.

At the state level, age- and sex-specific deaths, population sizes for states and territories between 1990 and 2020, sourced from the AHMD, were used as part of the input for calculating deaths attributable to $PM_{2.5}$. However, similar data at the GCCSAs level are not publicly available. For each GCCSA, we used age- and sex-specific population data (Estimated Resident Population, ERP) but only had total death counts from 2001 to 2020 provided by the ABS, without age and sex breakdowns. To estimate deaths by age and sex for each GCCSA, we applied the proportions of deaths from the state level, based on the following equation:

$$D_{a,s,g,st,t} = D_{g,st,t} \frac{D_{a,s,st,t}}{D_{st,t}}, \quad (1)$$

where $D_{a,s,g,st,t}$ represents the estimated deaths for age group a and sex s in GCCSAs g and state st for each year t between 2001 and 2020. $D_{g,st,t}$ is the total deaths in GCCSAs g and state st for the year t. $D_{a,s,st,t}$ is the deaths for age group a and sex s in the state st and year t, and $D_{st,t}$ is the total deaths in state for the same period. This approach assumes that the age and sex distribution of deaths in each GCCSAs is the same as in its respective state.

(2) Life-years lost attributable to $PM_{2.5}$

LYL is a component of life expectancy. In this study, LYL attributable to $PM_{2.5}$ measures the years lost due to $PM_{2.5}$ in the population before reaching 85 years of age. We calculated LYL by using deaths, population data, and life tables for ages 30 to 85 years.

To start the LYL calculation, we first calculated life expectancy between ages 30 and 85, denoted as ${}_{55}e_{30}$, which represents the average number of years lived by individuals in the population. The input of the standard life table calculation is the age-specific mortality rates (Preston et al., 2000). At the state level, we had all necessary information to input into the calculation from AHMD. However, for the GCCSAs level, life tables by age and sex in each GCCSA were not available from the ABS. Mortality rates for GCCSAs were calculated using the estimated age-and sex-specific deaths from equation (1), divided by the age- and sex-specific population in each GCCSA and time.

The total number of years between ages 30 and 85 is equal to the sum of life expectancy and LYL (life expectancy + LYL = 55) as shown in the following equation:

$$55 = {}_{55}e_{30}^{s,g,st,t} + {}_{55}\text{ə}_{30}^{s,g,st,t}\ , \tag{2}$$

where ${}_{55}\text{ə}_{30}^{s,g,st,t}$ represents the number of years lost for all causes from ages 30 to 85 by sex s, GCCSA g, state st, and time t. LYL are separated into two parts: attributable to $PM_{2.5}$ and the rest of the causes of death. The LYL can also be broken down by age group to determine their respective age-specific allocations as follows:

$$55 = {}_{55}e_{30}^{s,g,st,t} + {}_{30}\text{ə}_{30}^{s,g,st,t} + {}_{25}\text{ə}_{60}^{s,g,st,t}\ , \tag{3}$$

where life table notation is applied, with ${}_{y}\text{ə}_{x}$ representing the life-years lost between ages x and $x + y$. Detailed procedures for calculating LYL have been documented in previous studies (Andersen et al., 2013; Canudas-Romo et al., 2015; Erlangsen et al., 2017; Houle et al., 2024; Somboonsin et al., 2024).

3. Results

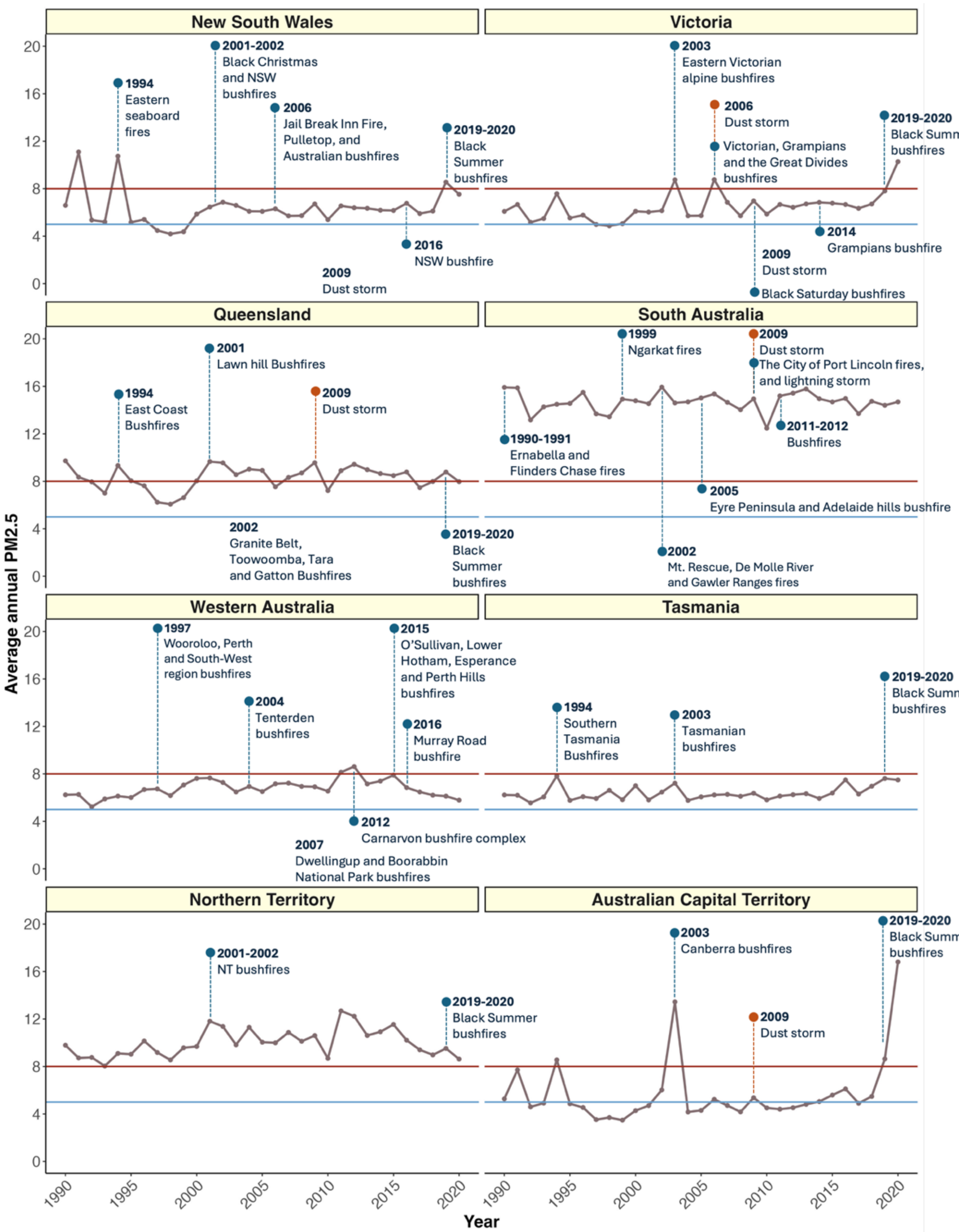

Figure 1. The concentration of $PM_{2.5}$ and the main causes of $PM_{2.5}$ in Australia from 1990 to 2020. The red lines represent the national standard for annual average $PM_{2.5}$ concentrations in Australia, set at 8 $\mu g/m^3$. The blue lines represent the WHO guideline for annual average $PM_{2.5}$ concentrations, updated in 2021, set at 5 $\mu g/m^3$. Red dots indicate causes from dust storms, and blue dots indicate causes from bushfires

Between 1990 and 2020, air particulate matter ($PM_{2.5}$) in Australia primarily originated from dust storms and bushfires. Figure 1 shows that the time trends of $PM_{2.5}$ in Australia fluctuated over the 30-year period, with peak levels corresponding to natural events. For example, in 2009, Australian dust storms significantly affected NSW, QLD, SA, and ACT, causing a noticeable increase in $PM_{2.5}$ levels compared to the previous year. Similarly, the major bushfires, known as the Black Summer bushfires, in 2019-2020 led to high $PM_{2.5}$ levels in many states.

The national standard for annual average $PM_{2.5}$ concentrations in Australia is set at 8 $\mu g/m^3$. However, the average annual $PM_{2.5}$ levels exceeded this standard in many years across all states, particularly during significant dust storms and bushfires. South Australia and the Northern Territory exceeded the national limit for most of the 30-year period, while Tasmania consistently remained below the national limit.

In comparison to the WHO guideline, which sets the annual average $PM_{2.5}$ concentration at 5 $\mu g/m^3$, all states generally stayed above this guideline throughout the years. Notably, ACT met the WHO guideline in some years prior to 2000.

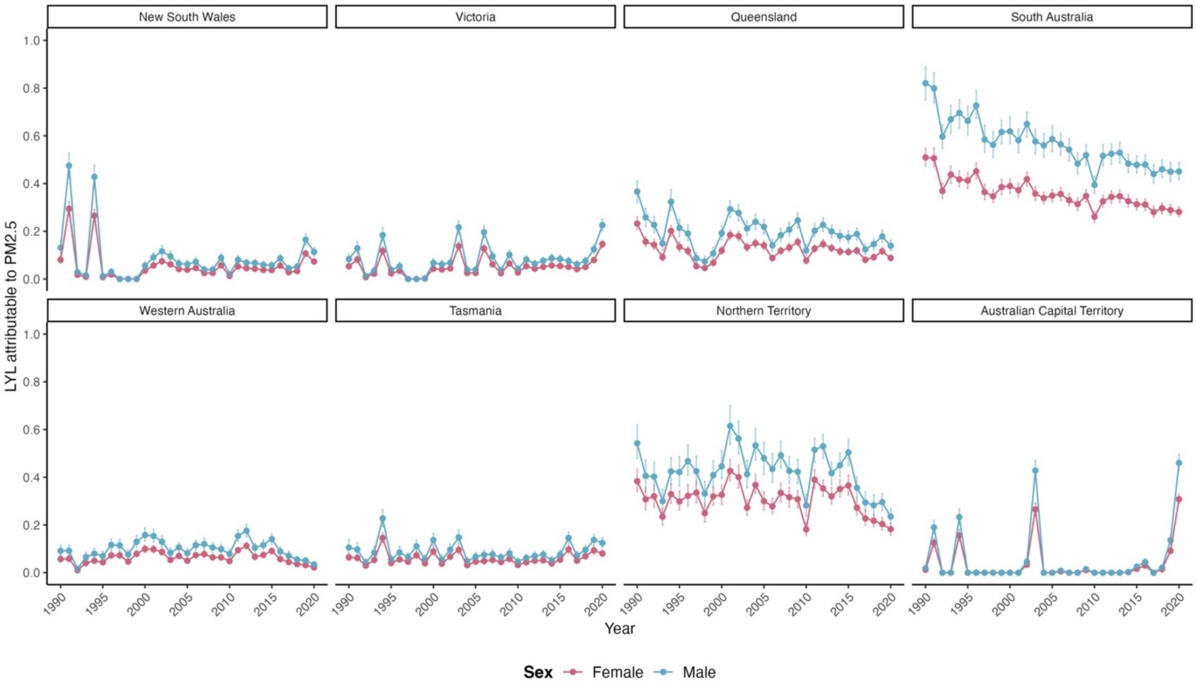

Figure 2. Life-years lost attributable to $PM_{2.5}$ by sex, 1990-2020.

LYL due to $PM_{2.5}$ did not show clear trends between regions from 1990 to 2020. However, males consistently had higher LYL than females in all regions. In SA, although LYL fluctuated, there was a general decreasing trend from 0.77 years in 1990 to 0.44 years in 2020 for females, and from 1.15 years in 1990 to 0.67 years in 2020 for males. Despite this decrease, LYL in SA remained higher compared to other states, and there was a wider gap between the sexes. NT ranked second in high LYL. The highest LYL in NT occurred in 2001, with 0.83 years for males and 0.61 years for females. In ACT, there was 0 LYL in many years, as the average $PM_{2.5}$ levels were low, and the calculation of deaths attributable to $PM_{2.5}$ from AirQ+ was 0. However, in certain years such as 1991, 1994, 2003, and 2020, there were high LYL in ACT with gender gaps of 0.08, 0.09, 0.22, and 0.22 years, respectively.

In NSW, VIC, and QLD, LYL fluctuated with noticeable peaks during major dust storms and bushfires, such as in 1991, 1994, 2003 and 2019-2020. WA and TAS showed relatively lower and more stable LYL compared to other states. However, males in these states also exhibited higher LYL compared to females, highlighting a consistent gender disparity across regions (Figure 2).

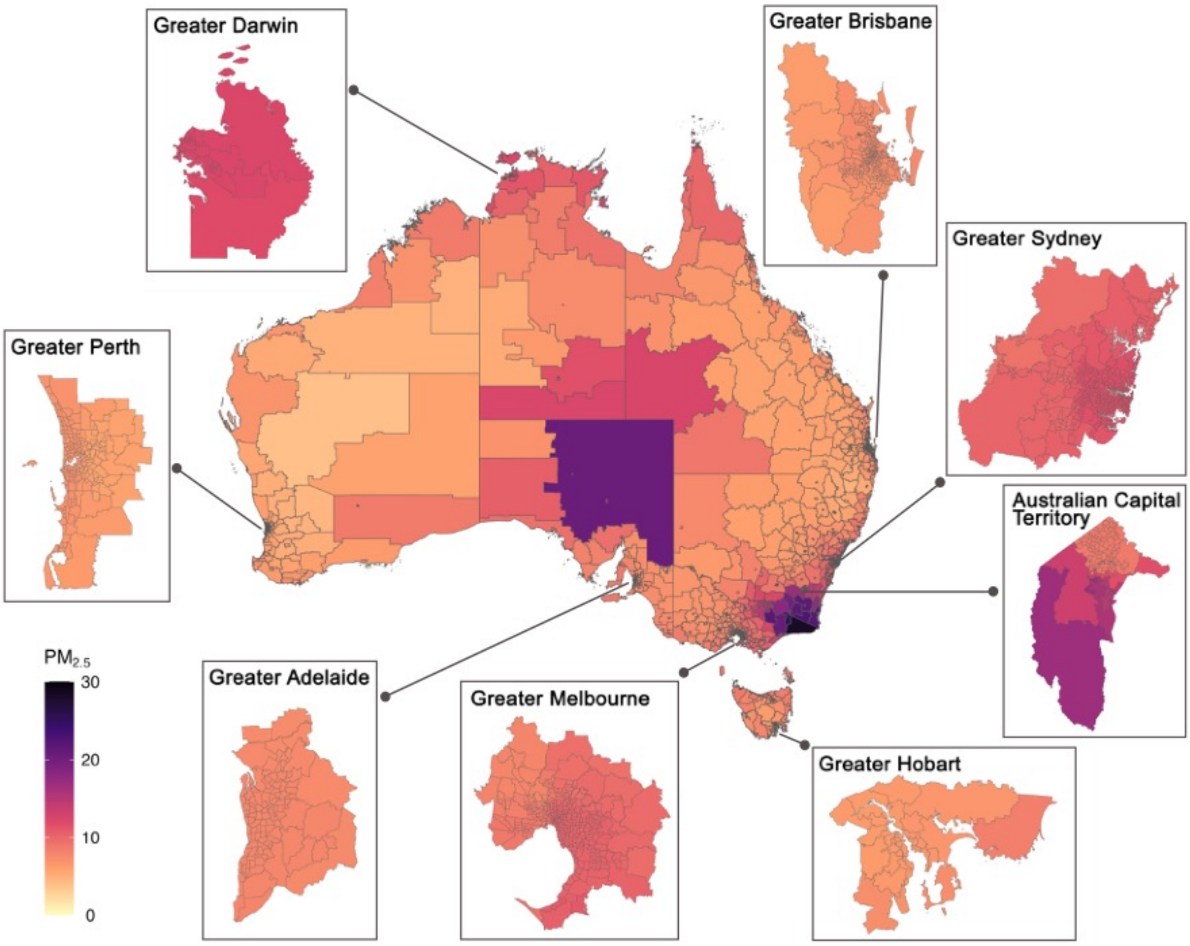

Figure 3. The concentration of $PM_{2.5}$ in 2020 across Australia.

In 2020, during the Black Summer bushfires, elevated levels of PM2.5 were recorded across many regions of Australia, with particularly high concentrations in SA, VIC, ACT, and NT. At the GCCSA level, as shown in Figure 3, significant regional variation in $PM_{2.5}$ concentrations was observed. Urban areas such as Greater Sydney, Greater Darwin, Greater Melbourne, and the ACT experienced particularly high levels of $PM_{2.5}$. Additionally, rural regions in SA and VIC exhibited concentrations exceeding 15 $\mu g/m^3$, with central desert areas of SA, NSW, NT, and VIC also showing concentrations above 10 $\mu g/m^3$, highlighting the widespread impact of the bushfires on air quality across the country.

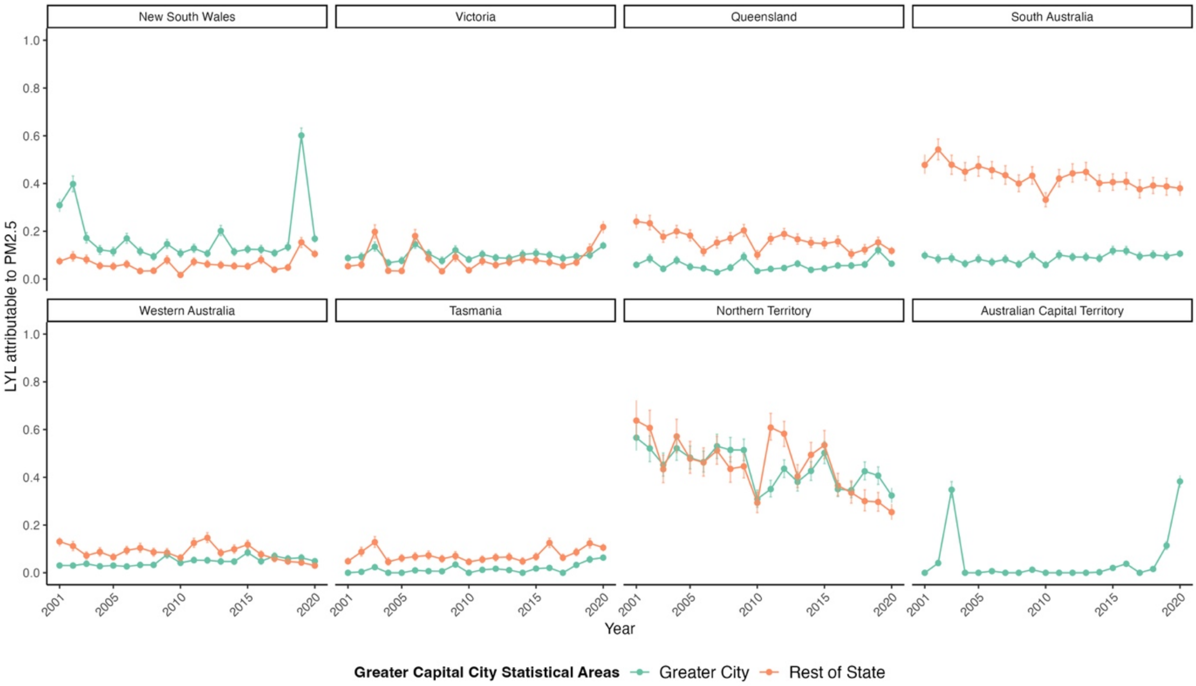

Figure 4. Life-years lost attributable to $PM_{2.5}$ by Greater Capital City Statistical Areas, 2001-2020.

Note: Names of Greater cities in each region: the first row, from left to right – Greater Sydney, Greater Melbourne, Greater Brisbane, Greater Adelaide; the second row, from left to right – Greater Perth, Greater Hobart, Greater Darwin, ACT.

Figure 4 presents LYL attributable to $PM_{2.5}$ by GCCSAs. Similar to Figure 2, there was no clear trend from 2001 to 2020. LYL for greater cities was consistently higher than for rest areas in NSW every year, with a significant gap in 2019, where Greater Sydney had 0.60 years of LYL compared to 0.15 years in the rest of NSW, resulting in a gap of 0.45 years. In VIC, although LYL in Greater Melbourne was higher than in the rest of VIC in many years, LYL in rest areas exceeded that of Greater Melbourne in 2003, 2006, and after 2019.

In contrast, LYL in rest of state was higher than in greater cities in QLD, SA, and TAS. A particularly large gap was observed in SA, where in 2002, the rest of SA had a higher LYL than Greater Adelaide by 0.46 years, followed by a difference of 0.39 years from 2003 to 2006. In WA, while the rest of WA had higher LYL than Greater Perth from 2001 to 2016, from 2017 onward, LYL in Greater Perth became lower than in the rest of the state.

In the NT, interestingly, LYL fluctuated with a decreasing, and there was no significant difference between urban and rural areas. However, from 2017 onward, LYL in Greater Darwin was likely higher than in the rest of NT.

ACT, which has a small geographic area with no separate urban and rural areas, exhibited high LYL in 2003 and 2020 at 0.35 and 0.38 years, respectively, corresponding to major bushfires in these two years.

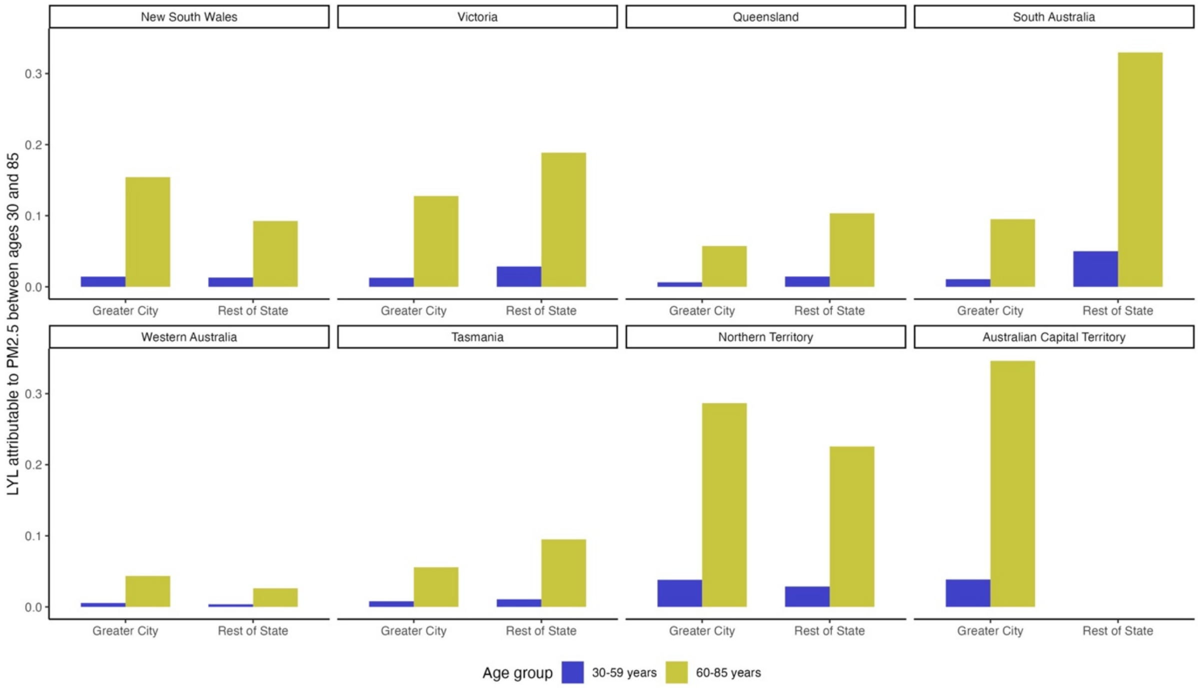

Figure 5. Life-years lost attributable to $PM_{2.5}$ by Greater Capital City Statistical Areas (GCCSAs) and age group in 2020.

Note: Names of Greater cities in each region: the first row, from left to right – Greater Sydney, Greater Melbourne, Greater Brisbane, Greater Adelaide; the second row, from left to right – Greater Perth, Greater Hobart, Greater Darwin, ACT.

When examining age differences, adults aged 30-59 years had lower LYL compared to the elderly aged 60 and over in all regions. In 2020, Figure 5 indicates that the elderly in the ACT experienced the highest LYL from PM2.5 pollution, accounting for 0.35 years. The elderly in the rural areas of SA ranked second with 0.33 years, followed by both the greater city and rest areas of the NT, which had LYL values of 0.29 and 0.23 years, respectively.

Among adults, both greater Perth and the rest of WA showed the lowest LYL in this year, with less than 0.1 year. Notably, LYL for adults in the rest of SA (0.05 years) was higher than LYL for the elderly in Greater Perth (0.04 years) and the rest of WA (0.03 years). Therefore, these results highlight significant regional and demographic disparities in LYL caused by PM2.5 in Australia over the past 30 years, with varying disparities observed between greater cities and rural areas due to natural events such as dust storms and bushfires, as well as consistently higher LYL for males and the elderly across all regions.

4. Conclusion

In summary, this study provides comprehensive information on how $PM_{2.5}$ pollution has affected Australian life expectancy over the past 30 years. Bushfires and dust storms are closely linked to elevated levels of $PM_{2.5}$ in the country, with years experiencing these events showing increases in LYL. Our findings also indicate that LYL among men was higher than among women across all regions. SA exhibited the highest LYL, particularly in its rural areas. The NT ranked second in LYL, with no significant difference between urban and rural areas. The ACT had the lowest LYL overall, but experienced higher levels in 2020 due to major bushfires. Furthermore, the elderly experienced a greater impact than adults in all regions. Addressing these disparities requires focused public health strategies and policies to reduce exposure to $PM_{2.5}$ and mitigate its adverse effects on life expectancy.

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