The carbon footprint of health care delivery in Western Australia's public health system

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Summary

Background Health systems have a dual imperative to take action on climate change. First, they must develop climate resilient health services in response to the direct and indirect impacts of climate change on health. Second, they must reduce their own carbon footprint since health systems are a significant contributor to global greenhouse gas emissions.

Methods An environmentally-extended multi-region input–output analysis was carried out, incorporating National Accounts data for Australia and annual expenditure data from WA Health for financial year 2019–20. Expenditure data were categorised to one of 344 economic sectors and by location of the provider of goods or services purchased.

Findings WA Health contributes 8% of WA's total carbon footprint, driven by expenditure on chemicals (23.8% of total), transport (20.2% of total), and electricity supply (19.7% of total). These 3 sectors represent 63.7% of WA Health's carbon footprint, but only 10.8% of its total expenditure.

Interpretation Reducing emissions related to health service provision in WA will require a holistic approach that leverages carbon footprinting insights and integrates them into organisational decision-making across all health programs. The high carbon-intensity of the transport and chemicals sectors supports previous research calling for a reduction in unnecessary pathology testing and the transition to delivery of non-urgent health care via sustainable models of telehealth. The impact of WA's size and location presents challenges, with a predominantly non-renewable energy supply and reliance on transport and supply chains from other states adding significantly to emissions.

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Keywords: Carbon footprint; Input–output analysis; Environmental impacts; Western Australia; GHG emissions

Introduction

Climate change is affecting human health in increasingly severe, unpredictable, and visible ways.[1] Human activity has increased the Earth's temperature by 1.1 °C since the start of the last century and the United Nations Intergovernmental Panel on Climate Change (IPCC) expects that warming will exceed 1.5 °C during this century, regardless of mitigation activities.[2] Human health gains are severely threatened by climate change as access to safe, clean, secure environments is undermined. Direct health impacts include injuries and death from extreme events such as bushfires, floods, and heatwaves, while indirect impacts are mediated by air pollution, waterborne diseases, changing vector distribution, and food safety and insecurity.[3,4] Climate change also exacerbates health inequities by disproportionatley affecting already vulnerable populations.[4]

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Research in context

Evidence before this study
Environmental impacts such as greenhouse gas emissions, water scarcity, and air pollution arise from the delivery of health services. Previous studies have analysed the carbon footprint of health care at a global and national level, and for some sub-national regions. As the public health care provider in Australia's largest state, WA Health manages one of the largest geographical health jurisdictions in the world, covering an area of 2.5 million km^2 and servicing a population of 2.7 million people.

Added value of this study
WA Health contributes 8% of Western Australia's carbon footprint, driven by its expenditure on chemicals, transport, and electricity supply. This study is the first of its kind assessment of an Australian state-based health sector

organisation, as it utilises high resolution expenditure data to analyse the health system's greenhouse gas emissions. The use of high-resolution expenditure data in a state-level health care carbon footprint assessment reveals the significance of procurement decisions in reducing greenhouse gas emissions implicated in the supply chains that support the delivery of health services.

Implications of all the available evidence
Embedding carbon emission data into management at all levels of WA Health, increasing the delivery of non-urgent health care via sustainable models of telehealth, reducing unnecessary pathology testing, and sourcing products from locations with a low-carbon electricity grid can support the reduction of WA Health's carbon footprint.

Health systems have a dual imperative in relation to climate change. First, they must adapt and respond to the increased human health impacts due to climate-related events which will increase demand on services. Second, the far-reaching operational and social footprint of the health sector means that it is a significant contributor to greenhouse gas (GHG) emissions. Therefore, health systems must mitigate their own contribution to climate change to reduce the flow-on effects to the health of patients and populations that they serve.[5]

Previous research into the carbon footprint associated with delivery of health care across 36 countries has shown that, on average, it contributes 5.5% of the total national carbon footprint.[6] A study of the carbon footprint of the English National Health Service (NHS) found that the majority of its GHG emissions (62%) were attributable to the supply chains which support clinical care, 24% were attributable to the direct delivery of care, 10% to staff commute and patient and visitor travel, and 4% to private health care services commissioned by the NHS.[7] In Australia, expenditure on the health sector produces 7% of the national carbon footprint,[8] while the health sector in New South Wales (NSW) contributes 6.6% of the state's GHG emissions.[9]

Western Australia (WA) is the largest state in Australia, spanning 2.5 million km^2 with a population of 2.7 million people,[10] and it is among the largest geographical areas in the world covered by a single health authority. Health care provision in WA is the responsibility of WA Health, comprised of the Department of Health and seven Health Service Providers.[11] Accounting for 31% of WA Government expenditure in financial year 2019–20, the health sector has been identified as a key pillar in the WA Government's commitment to transition to a low-carbon economy, and

an essential contributor in protecting the health of the community from the effects of climate change.[11]

To determine the most effective actions to deliver this commitment, it is important to understand the scale and characteristics of WA Health's GHG emissions—its carbon footprint. Previous studies of the health sector's carbon footprint have employed input–output analysis, which connects environmental impacts such as GHG emissions[12] and material use[13] to the economic activity that ultimately creates those impacts. These previous studies have faced data limitations, relying on publicly available information regarding expenditure directed to the health sector, rather than using a health organisation's own expenditure data as the key input to these calculations. For example, Pichler et al.[6] used health sector expenditure data from the Organisation for Economic Co-operation and Development for the 36 countries studied. Similarly, the carbon footprint assessments of the Australian health sector[8] and the sub-national analysis of the NSW health sector[9] relied on national health expenditure data from the Australian Institute of Health and Welfare.

In this study, we calculate WA Health's carbon footprint utilising input–output methodology and high-resolution expenditure data sourced directly from internal accounts for the 2019–20 financial year. This provides the most detailed assessment to date of any Australian health care system at a state level, and minimises the limitations associated with estimating expenditure values directed to each of the 344 economic sectors included in the input–output tables. The carbon footprint presented here is calculated based on the point at which WA Health spends money on the goods and services that support its operations, rather than at the point at which the patient spends money on the health care system, as has been the case in previous studies.

Methods

The carbon footprint for WA Health was calculated using environmentally-extended input–output methodology which connects an environmental impact (in this case, GHG emissions) to the monetary transactions within a given economic system for a given year. To do this, we built a custom multi-region input–output (MRIO) table using the Australian Industrial Ecology Laboratory (AusIELab),[14] featuring information on monetary transactions taking place between the eight states and territories in Australia and 344 industry and commodity sectors across the Australian economy.

Data

The custom-built MRIO table for financial year 2019–20 included three matrices. The first, the intermediate demand matrix (**T**), provided information on the value of economic transactions between each of the 5504 (344 industries + 344 commodities x 8 regions) region–sector combinations included in the MRIO table for that year. The 344 sectors that form the basis for this MRIO include all goods and services available for purchase by individuals, businesses, or government agencies within Australia. Next, the final demand matrix (**Y**) provided information on the total final demand for each of these region–sector combinations. Finally, the satellite matrix (**Q**) provided information on the 2020 GHG emissions associated with each of the 5504 region–sector combinations, measured in tonnes of CO_2 equivalent (CO_2-e).

Expenditure data for the 2019–20 financial year were obtained from the internal accounting records of WA Health. Initially, these were categorised according to WA Health's internal account codes and the state or territory where the expenditure was directed. In order to connect this expenditure to the MRIO table built within the AusIELab, a concordance matrix was created to allocate each of the WA Health account codes to one or more of the 344 economic sectors which form the basis of the MRIO table. This concordance matrix was used to generate a customised expenditure vector y_{WAH} (where WAH represents WA Health) for use in the input–output assessment described below.

This customised expenditure vector, y_{WAH}, captured all money spent by WA Health within Australia during the 2019–20 financial year in order to run its operations. This included expenditure on a wide range of goods such as prostheses, pharmaceuticals, food, chemicals, medical consumables, and equipment. Expenditure on services such as patient transport, facilities management, waste removal, linen supply and laundering, and other outsourced services was also included. This expenditure data was a key input to the input–output analysis described in the following section, which calculated results for each of the 344 economic sectors included in the MRIO table. These results were aggregated to higher level sectors for ease of presentation,

with information on the sectors included in these aggregations available in the Supplementary Material.

Data analysis

These data were used as inputs to mathematical calculations using input–output methodology, widely used in carbon footprint assessments.[6,8,12,15,16] This mathematical technique connects the greenhouse gases emitted at the point of production of a product, or delivery of a service, to the economic activity that creates the demand for that product or service. It takes advantage of the rigorous financial accounts kept by countries under the System of National Accounts framework[17] to generate the required MRIO tables, and the reporting of Nationally Determined Contributions required under the Paris Agreement[18] to provide GHG emissions data. When coupled with an entity's operating accounts, such as those provided by WA Health, this technique calculates the GHG emissions attributable to that entity's expenditure on products and services, emissions that accumulate along the supply chain transactions that support the delivery of those products and services to WA Health.

Input-output methodology is built around the Leontief Inverse (**L**), a matrix which provides information on the interdependencies within the economic system quantified by a given MRIO table. Once the custom-built MRIO table was generated, the Leontief Inverse (**L**) was calculated in a number of steps. First, the total output vector **x** for the economic system represented in the MRIO table was calculated from the summation of the intermediate demand matrix **T** and the final demand matrix **Y**. This output vector **x** was then diagonalised and inverted to provide $\widehat{\mathbf{X}}^{-1}$ which, when multiplied by the intermediate demand matrix **T**, provided the direct requirements matrix **A**. Finally, the Leontief Inverse **L** was calculated according to Equation (1), where **I** is an identity matrix with dimensions equal to those of **A**.

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \qquad \text{Equation (1)}$$

Once the Leontief Inverse (**L**) was calculated, it was used to connect the GHG emissions data represented in the satellite matrix (**Q**) with the expenditure data provided in the customised expenditure vector y_{WAH}, according to Equation (2).

$$f_{WAH} = \mathbf{q} * \mathbf{L} * \mathbf{y}_{WAH} \qquad \text{Equation (2)}$$

where f_{WAH} represents the carbon footprint associated with WA Health's expenditure and **q** represents the direct intensities matrix, calculated by multiplying the satellite matrix **Q** with $\widehat{\mathbf{X}}^{-1}$.

Data limitations

The need to allocate expenditure by an entity to the economic sectors included in the MRIO table introduces limitations to any input–output analysis, since the sector

taxonomies used by entities and those used by the statistical agencies that provide national accounts data are designed for different purposes. In this research, the sector taxonomy used in WA Health's internal reporting framework included 83 different account codes, which needed to be mapped to the 344 sectors included in the Australian MRIO. In many cases this mapping was straightforward with, for example, the WA Health account codes for accommodation mapped to the MRIO sector 'Accommodation', and the WA Health account code for bank fees mapped to the MRIO sector 'Banking'.

In some cases, there was not a direct match available between sectors, such as the 'Gas Power Water' account code which needed to be pro-rated to three sectors within the MRIO: 'Electricity supply'; 'Gas supply'; and 'Water supply: sewerage and drainage services'. In other cases, multiple WA Health account codes were mapped to just one of the MRIO sectors, reducing the ability to isolate the carbon footprint associated specifically with these account codes. The most notable example of this was the MRIO's 'Business services' sector, which includes the account codes related to all outsourced services such as facilities management, security management, administration, and waste management.

Other limitations may be introduced through the internal accounting procedures used by WA Health to allocate each expense to the appropriate internal account code. If there are errors in the allocation of expenses, these will be propagated through the input–output analysis since this expenditure is the key driver of the footprint results. Given the rigorous accounting procedures and guidelines in place for public health care in Australia as part of the Australian Hospital Patient Costing Standards,[19] this limitation is not expected to be material.

Limitations associated with the creation of MRIO tables using national input–output tables, such as those used in this research, have been discussed in detail previously,[20,21] and are not explored further here.

Ethics approval

No ethics approval was required for this study as it utilised routinely collected financial data. The purpose of this data is for the management of WA Health operations. No patient data or personally identifiable information was accessed or used in this study.

Role of the funding source

This work was partly funded by the WA Department of Health to enable development of a concordance of financial data with the AusIELab sectoral structure. WA Department of Health staff provided advice on the correct interpretation of financial data codes; however, the researchers remained independent of the funder. No authors received payment from a pharmaceutical company or other agency. All authors had access to the data used in the study and accept responsibility for the decision to submit the manuscript for publication.

Results

Our analysis quantified the total GHG emissions, or carbon footprint, for WA Health at 6578 kilotonnes (kt) of carbon dioxide equivalent (CO_2-e) for the 2019–20 financial year. In the same year, total GHG emissions for the state of WA were 82,116 kt CO_2-e,[22] which puts WA Health's carbon footprint at an estimated 8% of the state's total, and an estimated 1.3% of Australia's total emissions. This is consistent with previous research demonstrating that the health sector contributes 6.6% of the total emissions of NSW,[9] 7% of the total emissions of Australia,[8] and between 1.5% and 10% of emissions worldwide.[6,23]

Examination of these emissions in more detail provides information on the contribution that expenditure on each economic sector makes to WA Health's total carbon footprint. These sectors can be grouped into three overarching categories based on the degree of direct control the organisation has over the emissions and the location of the emissions[7]: Delivery of care, which contributes 32.4% of the total footprint and includes all emissions directly associated with the treatment of patients; Supply chain, which contributes 47.4% of the total footprint and incudes all emissions generated by the manufacture and delivery of products and services of suppliers upstream of the point at which care is delivered; and Transport, which contributes 20.2% and includes the intra- and inter-state movements of patients, staff, and goods. At an economic sector level, the top 12 sectors contributed 96.7% of WA Health's carbon footprint, with the highest contribution coming from expenditure on chemicals, at 24.8%. Fig. 1 illustrates the breakdown of WA Health's total carbon footprint by economic sector, and by category. The footprint generated by the top 12 sectors is also presented in Table 1, which includes a comparison of each sector's contribution to WA Health's carbon footprint alongside the share it represents of WA Health's expenditure. Information on the sub-sectors included in each of the aggregated sectors presented in Fig. 1 is available in the Supplementary Material.

Some activities undertaken to support WA Health's operations occur in locations outside WA. Table 2 provides a comparison of the proportion of expenditure directed at each state and territory compared to its share of WA Health's carbon footprint. An interesting finding here is that regions where the ratio of emissions to expenditure is higher (such as Queensland and Victoria) are also states where the electricity grid is more dependent on fossil fuels.[24] These states have higher carbon intensity in their supply chains, and therefore more carbon is embodied in the goods and services sourced from suppliers based there. On the other hand,
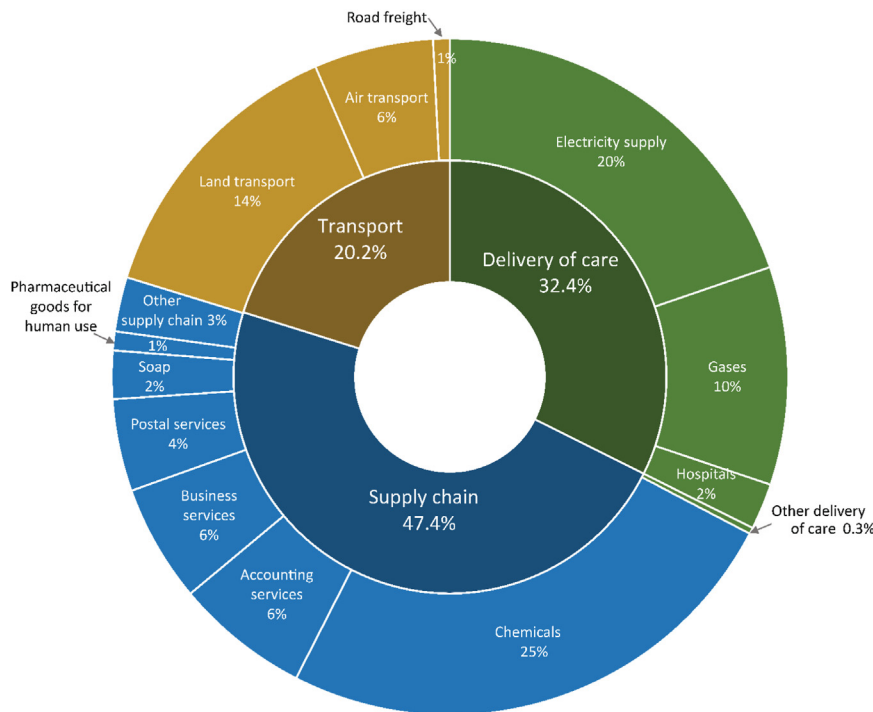
Fig. 1: Breakdown of WA Health's carbon footprint by sector and by category. Sectors have been categorised into: delivery of care, which includes all emissions directly associated with the treatment of patients; supply chain, which includes all the upstream activity required to enable delivery of care; and transport.

there are lower emissions despite higher expenditure in regions such as South Australia and the Australian Capital Territory, where renewable energy is a greater component of the electricity grid.[18]

Considering WA Health's carbon footprint by region provides insights into the contribution of different states and territories to the carbon footprint associated with each economic sector, as illustrated in Fig. 2. Two of the top 12 sector contributors to WA Health's carbon footprint were the Chemicals and Pharmaceutical goods sectors, both of which have strong supply chain links to NSW and Victoria. The Road freight sector also has a high attribution to NSW and Victoria; however, it is worth noting that intra-state road freight within WA still accounts for the majority (58.8%) of emissions attributable to this sector.

Rank	Sector	Footprint (kt CO$_2$-e)	% emissions	% expenditure
1	Chemicals	1629	24.8%	0.7%
2	Electricity supply	1298	19.7%	1.3%
3	Land transport	902	13.7%	8.2%
4	Gases	682	10.4%	0.3%
5	Accounting services	420	6.4%	1.8%
6	Air transport	374	5.7%	0.2%
7	Business services	369	5.6%	14.7%
8	Postal services	287	4.4%	0.1%
9	Soap and other detergents	151	2.3%	0.3%
10	Hospitals and nursing homes	142	2.2%	47.4%
11	Pharmaceutical goods for human use	59	0.9%	0.3%
12	Road freight	51	0.8%	0.4%
These 12 sectors contribute 96.7% of WA Health's total carbon footprint and represent 75.8% of expenditure.				

Table 1: Comparison of contribution to carbon footprint and share of total expenditure for the top 12 economic sectors contributing to WA Health's carbon footprint.

State or territory	Footprint (kt CO_2-e)	% emissions	% expenditure
Western Australia (WA)	5138	78.1%	72.0%
New South Wales (NSW)	712	10.8%	17.4%
Victoria (VIC)	497	7.6%	7.3%
Queensland (QLD)	186	2.8%	1.4%
South Australia (SA)	26	0.4%	0.9%
Australian Capital Territory (ACT)	16	0.2%	1.1%
Tasmania (TAS)	3	0.0%	0.1%
Northern Territory (NT)	0	0.0%	0.0%
Total	**6578**	**100%**	**100%**

Table 2: Comparison of contribution to carbon footprint and total expenditure for each state and territory.

Discussion

Health systems have substantial carbon footprints due to the broad scope of their operations. This includes: managing large campuses at multiple sites across wide geographical areas; operating continuously and consuming environmental resources for heating, cooling, water supply, and waste disposal; transporting patients and goods; and purchasing supplies and commissioning services from other organisations. The sources of GHG emissions for the WA Health system reflect common patterns seen in other health systems[6–9] with some additional findings due to the unique operating environment for delivering health services in Western Australia.

The transport sector makes a substantial contribution to WA Health's GHG emissions, at 20.2% of the total. This is not unexpected given WA's geographic size, with health services being delivered across an area of more than 2.5 million km². WA Health also relies on supply chains based in eastern states, which further increases the contribution of transport to its carbon footprint. Importantly, this analysis was based on expenditure by WA Health, and therefore it does not include GHG emissions generated by staff commuting to work or people visiting patients in hospital. Some transport services such as road freight may represent an unavoidable expenditure due to the vast geographic area and dispersed populations served by WA Health. However, the underlying need creating the demand for other transport services, such as movement of patients for non-urgent care, could be met through other means such as sustainable models of telehealth, which have been shown to reduce emissions with minimal adverse outcomes for some conditions.[25,26] Virtual or digitally enabled patient care pathways, such as Royal Perth Hospital's Hospital in Virtual Environments (HIVE) program[27] also have the potential to reduce emissions, although such programs must be designed carefully to
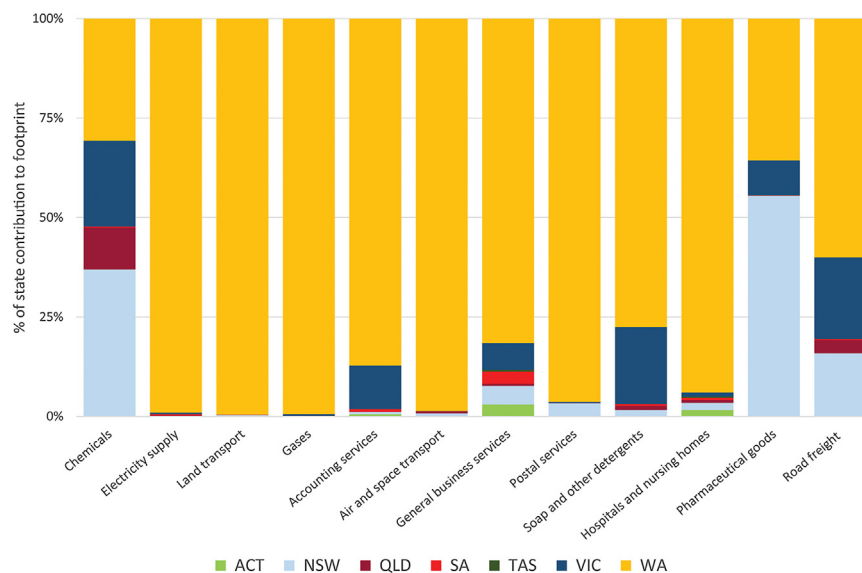

Fig. 2: Breakdown by region of expenditure for the top 12 economic sectors contributing to WA Health's carbon footprint.

avoid inadvertently introducing inequities and additional emissions.

The Chemicals sector also presents an opportunity for emissions reductions, as it generates 24.8% of the total carbon footprint but only comprises 0.7% of total expenditure. Products within this sector include diagnostic supplies, reagents, and culture media used in the pathology laboratory setting. The over-use of pathology testing in a clinical setting has been linked to low value care,[28] and a reduction in the number of unnecessary pathology tests has been identified as a potential avenue for reducing the carbon footprint of clinical care.[28,29] The results presented here would support this focus area and indicate that, over time, a reduction in expenditure on the chemical products that support pathology testing would facilitate a reduction in WA Health's carbon footprint. This approach can assist in bringing the carbon footprint into clinical decision-making, and assist health managers to achieve sustainable value in healthcare, defined by Mortimer and colleagues as creating positive outcomes for patients and populations while considering the 'triple bottom line' of environmental, social, and financial impacts.[30]

Electricity supply to WA Health also generates a significant share of the total carbon footprint, at 19.7%. This presents a short-term challenge in achieving reductions, since the energy system in WA remains fossil fuel dependent, with only 15% of electricity generated from renewable energy sources.[24] However, WA Health's facilities can invest in energy efficiency measures to reduce their emissions from electricity expenditure, as well as identify opportunities for electrification of sites in anticipation of the WA government's commitment to lower-emissions electricity and a decarbonised, renewable energy supply.[31] The difference in carbon intensity of the electricity grid in other states and territories presents another potential avenue for reducing the carbon footprint associated with WA Health's supply chains. As seen in Fig. 2 and 69% of the carbon footprint attributable to the supply of chemicals is generated in NSW, VIC, and QLD, all of which have high carbon intensity electricity grids.[24] Procuring from suppliers based in less carbon intensive regions, such as SA, TAS and the ACT, may reduce the carbon footprint associated with WA Health's supply chains.

Conclusion

This study of an Australian state-based health sector organisation utilises high resolution expenditure data to analyse the health system's greenhouse gas emissions. Our assessment has identified "carbon hotspots"—the economic sectors and locations of expenditure that make the greatest contribution to the GHG emissions generated by the provision of health services by WA Health.

These findings present an opportunity for WA Health to take a holistic approach to carbon emissions reduction by implementing specific initiatives to target the transport, energy, and chemicals sectors and to review its supply chain. These insights may be useful in developing a long-term program which allows WA Health to realise its potential to lead the state of Western Australia in its transition to a low carbon economy, while simultaneously protecting the health of the community from the effects of climate change.

Contributors
AM, AV, CB, and SJ conceptualised the study; AI, AM, and AV developed the data concordance; AI carried out data manipulation and analysis; CB and AI drafted the original manuscript, and all authors contributed to the final manuscript.

Declaration of interests
The authors declare no conflicts of interest. The author's views are their own and not necessarily those of the Western Australian State Government or WA Department of Health.

Appendix A. Supplementary data
Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2024.101115.

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