Perinatal Health Surveillance: A Spatiotemporal Analysis of Administrative Health Records from Queensland, Australia, 2008–2018

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Abstract

Research into the spatial and temporal distribution of perinatal health across Queensland, Australia, remains limited. This is despite studies within perinatal epidemiology supporting the importance of exploring spatial trends to identify the geographical distribution of vulnerable groups requiring intervention or further research. The purpose of this study was to explore spatial and temporal trends in perinatal health and antenatal service utilisation across Queensland, Australia. Space-time pattern mining and spatial autocorrelation geographic information system methods were used to analyse administrative perinatal records collected between 2008 and 2018. Changes in perinatal health and antenatal service utilisation over space and time were reported. Areas in *Remote* and *Very remote* parts of Far North Queensland with increasing birth rates over the study period were also identified as hot spots for high proportions of low birthweight births and smoking during pregnancy. Both remote and regional areas of northern Queensland were hot spots for high proportions of public antenatal care visits, while hot spots for private visits were in *Major cities*. This small-area exploration of perinatal health highlights the value of administrative records in monitoring location-based perinatal health outcomes and service use. This can be crucial in monitoring perinatal indicators over time, exploring associations between maternal environment and health outcomes, tracking the impact of health interventions, and identifying marginalised groups.

Keywords: GIS, space-time**,** perinatal health, emerging hot spot

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Parayiwa, C., Behie, A. M., & Lal, A. (2022). Perinatal health surveillance: A spatiotemporal analysis of administrative health records from Queensland, Australia, 2008–2018. *Proceedings of The Royal Society of Queensland*, *131*, 35–50. https://doi.org/10.53060/prsq.2022-09 (see supplementary material online)

Introduction

Where we live influences our health. Spatial and temporal analysis of small-area data plays a crucial role in understanding and monitoring local trends in population health, developing targeted health interventions, and prioritising the allocation of health resources (Wang, 2020). The state of Queensland covers an area of just under 1.5 million square kilometres with an estimated population of over 4 million residents (ABS, 2018a). Located in Australia's north-east, Queensland has over 7000 km of coastline along which over 80% of its population resides. The majority of remaining areas in the state are categorised as *Remote* or *Very remote* based on their relatively limited access to service centres (Figure 1) (Queensland, 2019a).

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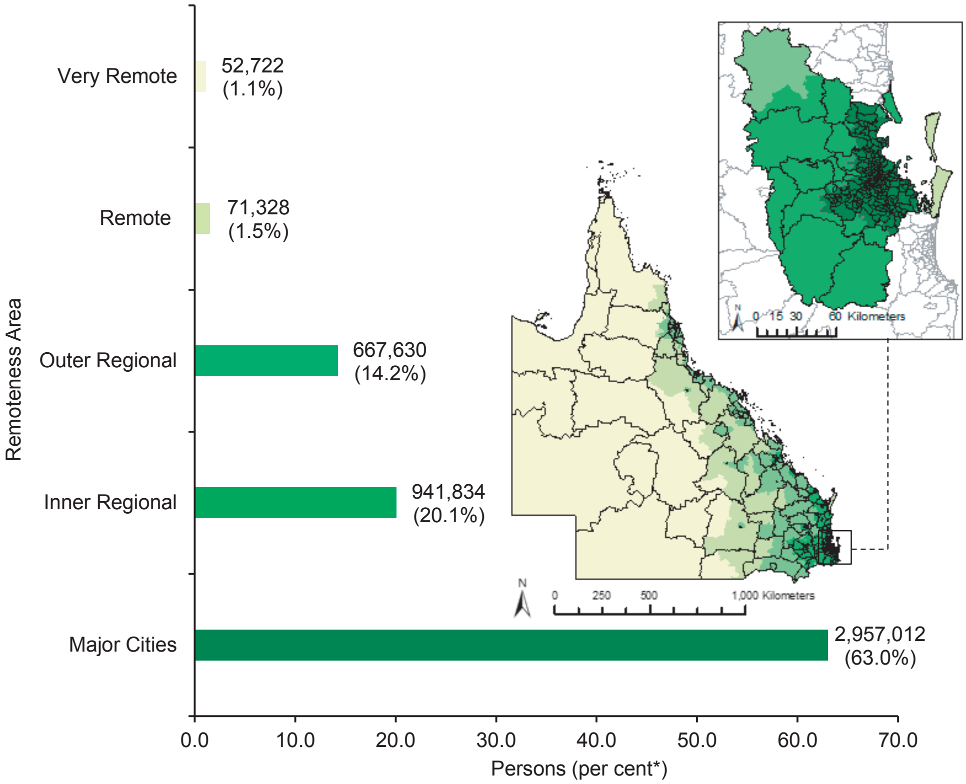

FIGURE 1. Bar graph presents Queensland 2016 population by Remoteness Area. Map inset presents Queensland 2016 Remoteness Areas and 2016 Statistical Area 2 census area boundaries in Greater Brisbane. *Data Source:* Author analysis of ABS 2016 Census TableBuilder.

* Percentages calculated as a proportion of total population by place of usual residence (excludes Migratory-Offshore-Shipping and no usual address).

Queensland's geographical variation in population distribution and remoteness limits the informative value of state-level data. Such data can restrict the identification and monitoring of the health, over time, for smaller populations in remote communities. Once aggregated, their health outcomes are combined with those of larger populations residing in incomparably distinct, and commonly more urban, locations (AIHW, 2022b).

The perinatal period is defined by the World Health Organization (WHO) as commencing at 22 weeks of gestation and ending seven days after birth (WHO, 2022). A mother's location during this period can influence her pregnancy outcomes through her neighbourhood quality (e.g. green spaces, transportation access, availability of core services, condition of buildings/streets, etc.), exposure to extreme weather events, and access and travel time to healthcare providers (Ali et al., 2018). Since 2010, studies using geographic information systems (GIS) to explore maternal health have been on the rise, analysing spatial trends and additional factors such as demographics, socio-economic status, distribution of health services, and education. Examples include an exploration of spatial trends in adverse outcomes such as preterm and low birthweight incidence in Ethiopia (Adeleke et al., 2020), Canada (Seabrook et al., 2019), the United States (Bloch, 2011) and Indonesia (Donal et al., 2018). The relationship between maternal location and antenatal service use has also been studied. Studies exploring greenspace access and perinatal health outcomes in South Carolina, USA (Runkle et al., 2022) and Sydney, Australia (Akaraci et al.,

2021) found an association between maternal location and an increased risk of adverse birth outcomes. A similar association was made between adverse outcome risk and post-natal care usage in Ethiopia, Africa (Sisay et al., 2019). Despite the breadth of existing research, a review of over 5000 articles, at the time of this study, found that most research making use of GIS to explore maternal health came from countries in Africa, Asia, Latin America and the Caribbean (Ahmadian et al., 2020) with limited research originating from Australia.

Perinatal health is measured through both maternal and infant characteristics present during the perinatal period, such as antenatal care provision, maternal behaviour during pregnancy and birth outcomes, all of which can be captured in administrative records. In Australia, consistently collected government administrative health records provide a validated, population-based dataset to analyse small-area perinatal health indicators such as smoking during pregnancy, and preterm and low birthweight births (AIHW, 2022a).

Smoking during pregnancy is a risk factor for miscarriage, low birthweight, premature births, and a wide range of birth defects that have long-term impacts on infant health (Lange et al., 2018). Despite the immediate and long-term health implications of smoking for both the mother and unborn child, 9.2% of Australian mothers were recorded as smoking during pregnancy in 2020 (AIHW, 2022a). Gestational age and infant weight at birth are common indicators of infant mortality and morbidity risk from birth. Within the Developmental Origins of Health and Disease (DOHaD) hypothesis, such indicators can be used to measure and understand the influence of the early life environment, pre- and post-natal, on health and disease risk both at birth and across the life course (Penkler et al., 2019). Infants born prematurely (<37 weeks gestation) or at a low birthweight (<2500 grams) are at an increased risk of higher mortality and morbidity at birth and in later life. They have also been found to be at an increased risk of developing chronic non-communicable diseases in adulthood (de Mendonça et al., 2020). Low birthweight births in an Australian Aboriginal community in the Northern Territory, for example, were found to be at a higher risk of later-life natural deaths, particularly cardiovascular and renal deaths, than non-low birthweight births (Hoy & Nicol, 2019). Similarly, low birthweight babies in the same communities were found to have a higher risk of cardiovascular disease hospitalisations in adult life (Arnold et al., 2016).

Access to appropriate antenatal care throughout pregnancy is associated with reduced complications as it involves regular screening for sexually transmitted infections, high blood pressure and gestational diabetes while monitoring for potential high-risk behaviours such as smoking during pregnancy (WHO, 2012). Communities in *Remote* and *Very remote* areas of Australia face location-based vulnerabilities. This is driven by barriers to accessing consistent and holistic (specialty and general) health services when compared to more urban areas, which can increase the risk of adverse health outcomes (AIHW, 2022a). Informed planning for perinatal health over space and time is crucial to mitigate this ongoing societal and locational disparity. Australian healthcare policy has long acknowledged the importance of geography and population characteristics when evaluating health outcomes. Ongoing health strategies have engaged with sector experts, researchers and policy makers to support equitable access to maternity and birthing services for the vulnerable. They have additionally focused on outcomes within communities and factored in geographic characteristics such as remoteness, socio-economic status and links to medical specialists (Pilcher et al., 2014). This study aims to apply spatiotemporal analytical methods using administrative health records to highlight significant perinatal health trends over space and time in the state of Queensland. Analysing spatial clustering of perinatal health and antenatal care service use will help identify areas for targeted region-specific health service interventions and further research that would support ongoing development of effective perinatal healthcare provision.

Materials and Methods

Study Sample

The Queensland Perinatal Data Collection (QPDC) is a population-based, cross-sectional dataset that includes data items that comply with the Perinatal National Minimum Data Set (P-NMDS) managed by the Australian Institute of Health and Welfare (AIHW). P-NMDS guidelines support consistent collection of data on births in each state and territory. The QPDC monitors patterns of obstetric and neonatal practice across the state, providing statistical information to service providers, policy developers and researchers. The QPDC includes all live births and stillbirths of at least 20 weeks gestation or at least 400 grams in weight (Queensland, 2019c).

Data for 666,803 births collected under the QPDC, from July 2008 to June 2018, where maternal state of usual residence was Queensland, were spatially analysed using STATA statistical software and Esri ArcGis Pro spatial software. The financial period (30 June to 1 July) in which each birth occurred was applied as the time step, and census areas were used to allocate maternal location. Changes in livebirths over time within a census area were explored using crude birth rates. The proportion of preterm and low birthweight births, smoking during pregnancy, and antenatal care provider visits, were used as indicators of perinatal health outcomes and service use (Supplementary Table 1). Antenatal care was defined as a visit between a pregnant mother and a midwife or doctor (AIHW, 2022a). Care providers included midwifery, medical, and general practitioners providing health services for the pregnancy recorded (Table 1). Due to small numbers (cell size of less than 10), incidences of preterm and low birthweight births, and smoking during pregnancy were spatially explored at the Statistical Area 2 (SA2) level using three years of aggregated data (2016–2018).

Table 1. Definitions of antenatal care providers and perinatal health indicators as reported by the Queensland Perinatal Data Collection. Adapted from (Queensland, 2017b).

Data item	Definition
Antenatal care providers	
Midwifery practitioner – Public hospital/clinic	Includes public hospital clinics, hospital-based midwifery clinics and community-based midwifery programs run by nursing staff.
Medical practitioner – Public hospital/clinic	Includes hospitals and hospital-based clinics attended by medical staff.
Medical practitioner – Private – General practitioner	Includes medical officers in a general practice.
Medical practitioner – Private – Specialist	Includes a private specialist medical practitioner in their own private practice (e.g. private obstetrician).
Midwifery practitioner – Private	Includes registered midwives practising in the community.
Perinatal health indicators	
Preterm	Liveborn singleton births at less than 37 weeks gestation as a proportion of the total liveborn singleton births from July 2016 to June 2018.
Low birthweight	Liveborn singleton births weighing less than 2500 grams as a proportion of the total liveborn singleton births from July 2016 to June 2018.
Smoking during pregnancy	Mothers who smoked at any point during a pregnancy as a proportion of mothers with a stated smoking status.

Geographical Concordance

Census-based geographical areas are frequently used in the spatial analysis of population data within perinatal epidemiology such as by Bloch et al's 2011 study into preterm birth disparities across the state of Philadelphia in the USA. In our study, births were assigned to a location using maternal usual residence collected in the QPDC as Statistical Local Area (SLA) census areas until 2011–2012 and updated to Statistical Areas level 2 (SA2) census areas from 2012–2013 onwards (Supplementary Table 2). SA2s and SLAs were coded as defined by the ABS Australian Statistical Geography Standard (ASGS) and the Australian Standard Geographical Classification (ASGC), respectively (ABS, 2010, 2016).

SA2s represent communities that interact together socially and economically with a population range of generally 3000 to 25,000 persons[a] (ABS, 2016). For comparisons over space and time, all births recorded in both SLAs and SA2s were concorded to the same ASGS 2016 SA2 census areas. Concordances are a mathematical method of reassigning data from one geographic region to another region. The ABS produces publicly available concordance files developed using population-weighted grids (ABS, 2012b). This study made use of population-based birth records aligning with the population weighting of applied concordance. Researchers proceeded with data concordance as the ABS public release of associated files deemed the concordance of an acceptable overall quality (ABS, 2012a).

Spatial Autocorrelation

To identify point-in-time spatial clustering of perinatal health indicators, spatial autocorrelation was applied using Global Moran's *I* and Getis-Ord G_i* statistics. A method previously used in exploring spatial patterns in maternal and child healthcare utilisation across distinct regions in Ethiopia (Defar, Okwaraji, Tigabu, Persson, & Alemu, 2019). Global Moran's *I* measured the degree of spatial correlation between adjacent SA2s by analysing both SA2 location and recorded data (births). A Moran's *I* score of 0.3 or more indicated significant positive spatial autocorrelation supporting the non-random clustering of SA2s with similar values. The Getis-Ord G_i* statistic allowed for the point-in-time visual presentation of significant SA2 clusters of high or low values. The *p* value and z-score developed a G_i score used to thematically map hot and cold spots of significantly clustered areas. Whereby hot spots indicated significant clustering of similar data values and cold spots were indicative of significant dispersion of data across neighbouring SA2s.

Space-time Pattern Mining

To explore changing patterns in birth rates over time, space-time pattern mining methods were applied, as was done by Naqvi et al. (2021) in their spatiotemporal investigation of Dengue Fever in Pakistan and as used by Nielsen et al. (2019) in their exploration of small for gestational age and low birthweight births in Alberta, Canada. SA2s were entered as the location ID, the time step was set as financial year, and the bin data value was set as the crude rate of livebirths per 1000 estimated resident population (ABS, 2012c). Commonly, space-time mining includes the aggregation of point data to determine significant clustering as done in referenced studies; however, to accommodate administrative population data grouped by census areas, a space-time cube (Supplementary Figure 1) was created from defined locations in ArcGIS Pro using SA2 polygons and birth rate per year to create a network Common Data Form (netCDF) file (Esri, 2019a). The netCDF file was imputed into the ArcGIS Pro Emerging Hot Spot Analysis tool which analysed changes in annual birth rates using a space-time implementation of the Getis-Ord G_i* statistic. A spatial relationship between neighbouring SA2 polygons was determined using *contiguity edges only* to factor in the variable sizes of SA2 polygons. The global value was set using individual time steps so each SA2 birth rate was analysed in comparison to the space-time bins in the same time step. Analysis outputs presented a two-dimensional representation of emerging hot and cold spot trends analysed using the Mann-Kendall trend statistic to run rank correlation analysis for birth rates in respective time periods. The trend for each bin series was recorded as a z-score and *p* value. A positive z-score supported an increase in birth rates, a negative z-score indicated a decrease in birth rates over time, and a low *p* value (<.05) supported a statistically significant trend (Esri, 2019b).

Results

Birth Rates and Perinatal Health

Significant emerging hot (increasing trend) or cold (decreasing trend) spots in birth rates were reported in 143 of 510 mapped Queensland SA2s between 01 July 2008 and 30 June 2018. Overall, there was a trend of decreasing birth rates across Queensland SA2s from 2008 to 2018 (z-score = –3.94, *P*<.001) (Table 1). Of the 69 emerging hot

[a] SA2s can fall out of this target population range due to sparse populations in remote areas spread over large and geographically diverse regions, isolated areas such as islands, and arbitrary subdivisions such as large suburbs or regional towns (ABS, 2016).

spots of increasing birth rates, the majority (>50%) included SA2s in *Remote* and *Very remote* areas of northern Queensland, areas along the state's coastline, and in the state capital of Brisbane (Figure 2). Persistent, sporadic, and consecutive trends were indicative of areas where births rates were relatively stable (consistent rates over time), while new, diminishing and intensifying trends highlighted areas with significant changes in birth rates over time (Table 2, Supplementary Table 3).

Table 2. Results of emerging hot spot analysis (neighbourhood time step) of births per 1000 estimated resident population. Queensland, Statistical Area 2, 01 July 2008 to 30 June 2018.

Space-time trend	Hot spots	Cold spots
New	6	4
Consecutive	19	21
Intensifying	2	2
Persistent	16	9
Diminishing	4	5
Sporadic	22	33
Oscillating	0	0
Historical	0	0
Total	**69**	**74**

Although areas in northern Queensland had significant hot spots for high birth rates relative to surrounding SA2s, birth rates in individual SA2s decreased over the time of this study. For example, Cape York's birth rate decreased from 17.3 to 13.3 births per 1000 population. The same areas with emerging hot spots for high birth rates also had hot spots for high proportions of low birthweight births (Figure 3a & 3b), preterm births (Figure 3c & 3d) and smoking during pregnancy (Figure 3e & 3f) in 2016–2018.

The largest increase in birth rates was recorded in Newtown, Toowoomba, up from 17.6 to 37.0 births per 1000 population (Figure 2). In 2016–2018, Newtown was part of a significant hot spot cluster for high proportions of low birthweight and preterm births, recording 7.1% and 10.0%, respectively (Figure 3a & 3c). Toowoomba also had new hot spots identified in Wilsonton and Toowoomba-West SA2s. Despite having no significant trends in birth rates over time (Figure 2), Redland Islands off the coast of Greater Brisbane, classified as *Remote* (Figure 1), presented a significant hot spot for high proportions of all three perinatal health indicators: low birthweight births (Figure 3b), preterm births (Figure 3d), and smoking during pregnancy (Figure 3f).

Overall, the distribution of perinatal health indicators varied across Queensland SA2 areas in 2016–2018. Significant clustering of preterm (Moran's I=0.19, z-score=6.11, P<.001) and low birthweight (Moran's I=0.11, z-score=3.55, P<.001) births was supported throughout the state. Palm Island off the coast of Townsville recorded the highest proportion of preterm births (15.0%), and Yarrabah east of Cairns recorded the highest proportion of low birthweight births (13.0%). Significant hot spot clustering of smoking during pregnancy (Moran's I=0.55, z-score=17.31, P<.001) was mainly identified in *Remote* and *Very remote* parts of the state (Figure 1). The highest proportion of smoking during pregnancy was recorded in Kowanyayama-Pormpuraaw (59.4%) in Far North Queensland (Figure 3).

Antenatal Care Providers

From 2008 to 2018, women giving birth in Queensland had over one million recorded antenatal care visits during pregnancy, which varied over space and time. During this time, public providers made up the highest proportion of reported antenatal care providers, with an increase in public midwifery practitioners from 26.9% to 35.9% of antenatal care visits in 2017–2018 (Figure 4).

In 2016–2018, combined antenatal care visits followed a similar pattern, with public antenatal care providers making up the highest proportion of care used by mothers (66.1% of recorded antenatal care use over the period). Private general practitioners continued to make up the largest proportion of private antenatal care used (Supplementary Figure 2). Spatially, significant clustering of high proportions of *public midwifery practitioner* use occurred in *Remote* and *Very remote* areas of Queensland and Stradbroke Island off the coast of Greater Brisbane (Moran's I=0.46, z-score=15.94, P<.001), while high proportions of *private general practitioner* use had significant hot spot clusters in the capital Greater Brisbane area (Moran's I=0.69, z-score=20.73, P<.001) (Figure 5).

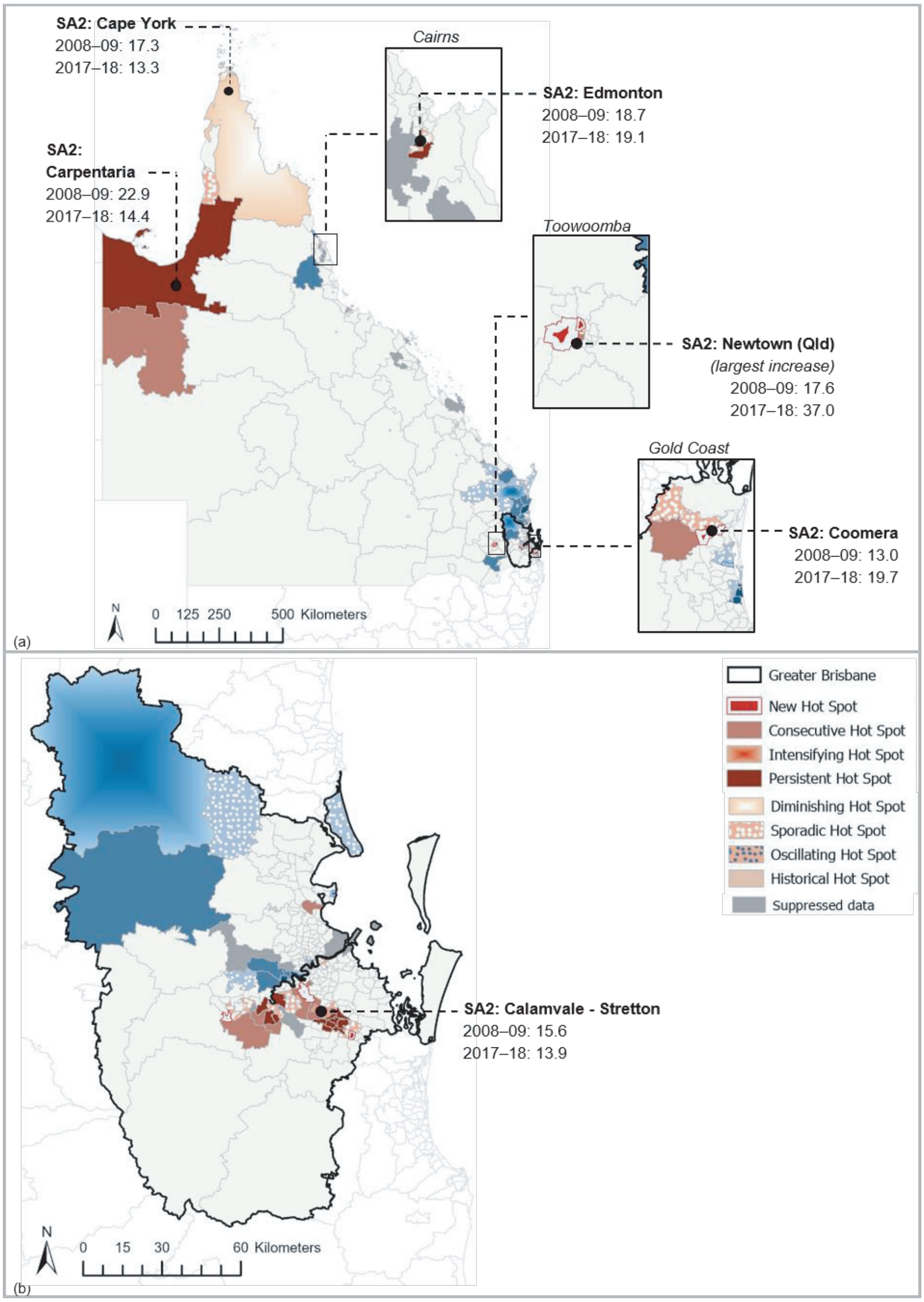

FIGURE 2. Statistical Area 2 (SA2) emerging hot spot analysis of crude birth rate (livebirths per 1000 estimated resident population) from 01 July 2008 to 30 June 2018 in Queensland with (a) state and (b) greater capital city, Greater Brisbane, results (*n=603,845*). Data suppressed where estimated resident population less than 1000 or number of births less than 100. *Data Source*: Queensland Perinatal Data Collection, 01 July 2008 to 30 June 2018.

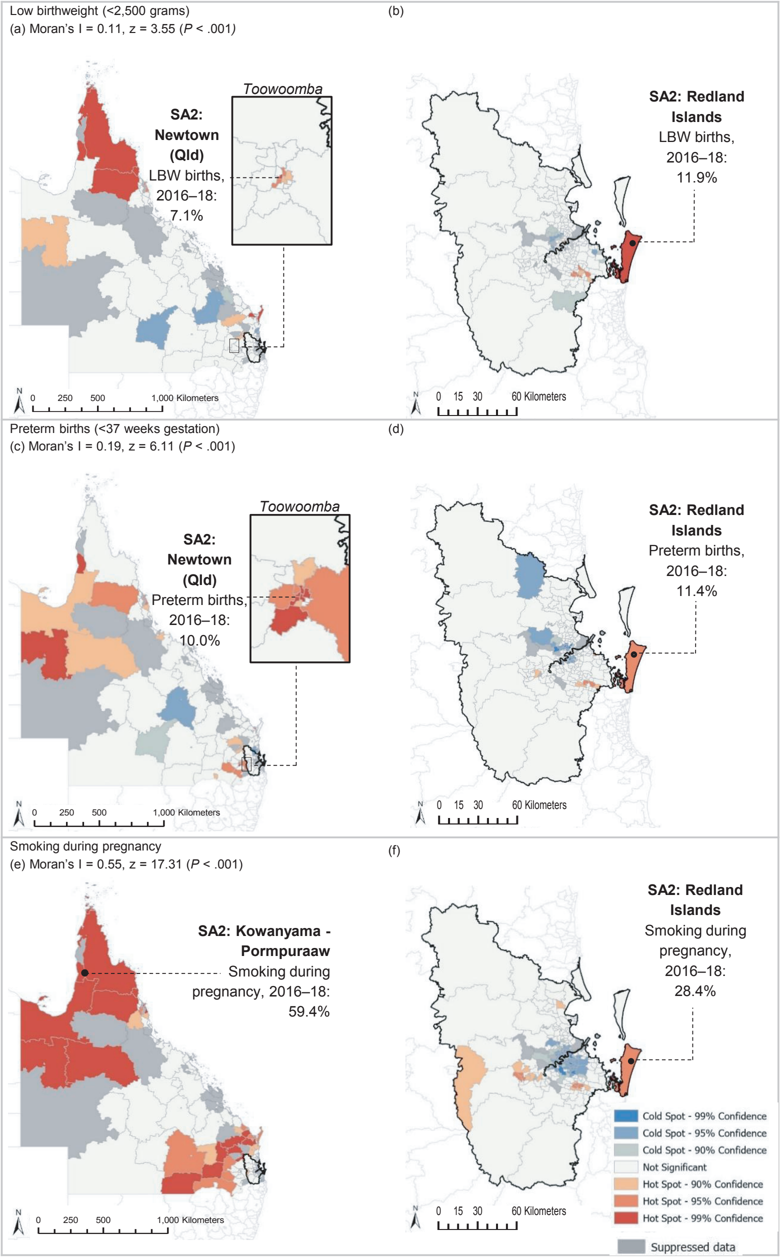

FIGURE 3. Getis Ord G_i^* hot spot analysis output maps for Queensland and Greater Brisbane by Statistical Area 2 census areas between 2016 and 2018 for: (a) and (b) low birthweight births (<2500 g) as a proportion of singleton livebirths where weight at birth known (*n*=9138); (c) and (d) preterm births (<37 weeks gestation) as a proportion of singleton livebirths where gestational age known (*n*=12,025); (e) and (f) smoking during pregnancy as a proportion of mothers where smoking status during pregnancy known (*n*=17,020). Data suppressed where number of singleton livebirths or mothers with recorded smoking status during pregnancy less than 100. *Data Source*: Queensland Perinatal Data Collection, 01 July 2016 to 30 June 2018.

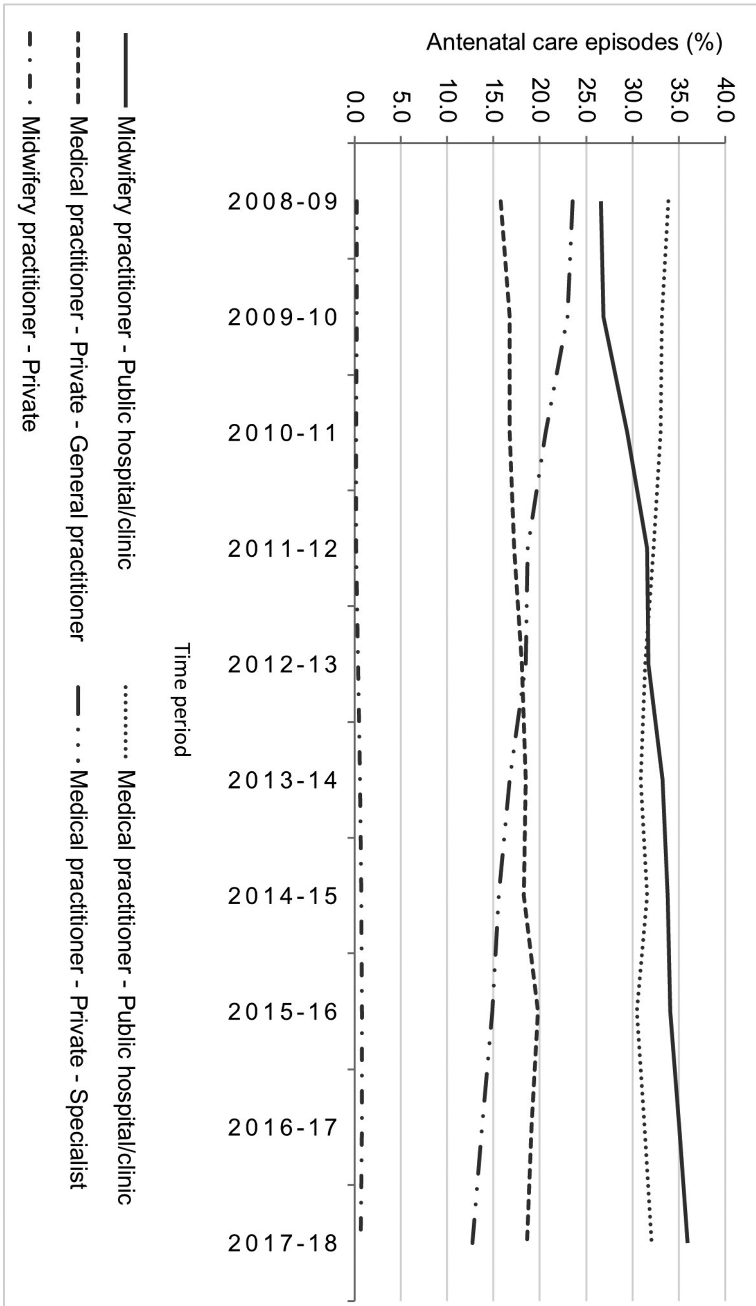

FIGURE 4. Recorded antenatal care visits in Queensland from 01 July 2008 to 30 June 2018 by service provider. Recorded antenatal care providers presented as a proportion of total births where antenatal care provider known. Most antenatal care was sought from public healthcare providers and, over the study period, use of public midwifery practitioners and private general practitioners increased (n=1,951,309). *Note*: A mother can seek support from different antenatal care providers during the same pregnancy.

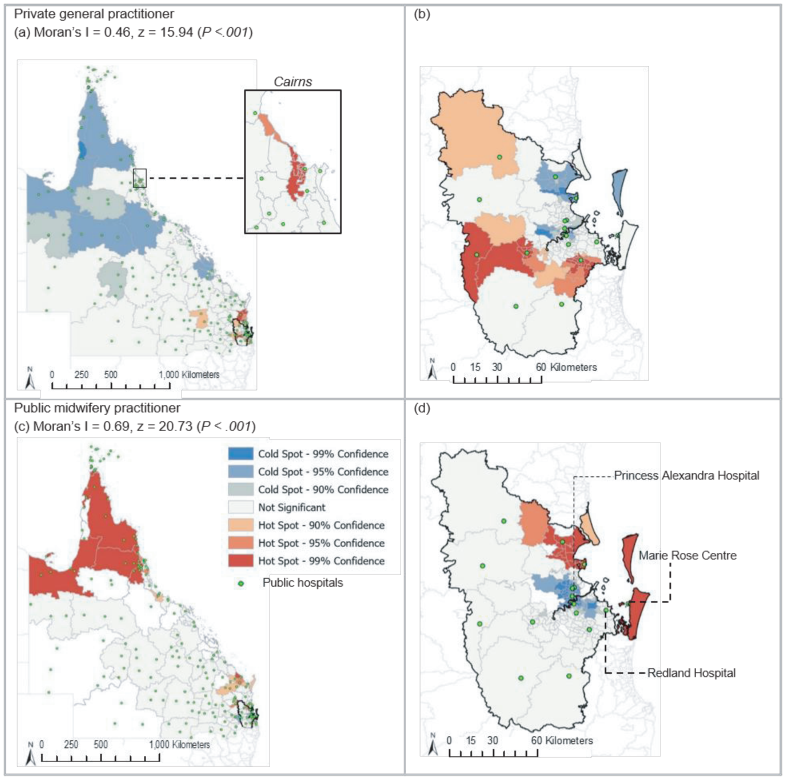

FIGURE 5. Statistical Area 2 (SA2) Getis Ord G_i* hot spot analysis of 'Medical practitioner – Private – General practitioner' (a) and (b); and 'Midwifery practitioner – Public hospital/clinic' (c) and (d) antenatal care providers as a proportion of all stated providers in Queensland between 2016 and 2018. Hot spots for high proportions of 'Medical practitioner – Private – General practitioner' identified in *Inner* and *Outer regional* areas and *Major cities*, *n*=22,816. Hot spots for high proportions of 'Midwifery practitioner – Public hospital/clinic' identified in *Remote* to *Very remote* areas of Queensland, *n*=50,642. *Data Source*: Queensland Perinatal Data Collection, 01 July 2016 to 30 June 2018.

Discussion

The crude birth rate for the state of Queensland has decreased from 15.0 per 1000 population in 2008 to 12.4 in 2018 (ABS, 2019a). Using space-time pattern analysis for the first time on Queensland perinatal data, this study identified areas with increasing birth rates over time (emerging hot spots) and point-in-time hot spots for high proportions of poor perinatal health outcomes. The Toowoomba region exemplified a pattern of increasing birth rates and clustering of poor perinatal health. The region had the largest increase in birth rates in the Newtown SA2 and hot spots identified in Wilsonton and Toowoomba-West. SA2s in Toowoomba were found to have significant hot spots of high proportions of low birthweight and preterm births. This overlap in increasing birth rates and high proportions of low birthweight and preterm births is important when looking at maternal and health service characteristics within these regions. The city of Toowoomba is situated roughly 110 km west of Brisbane, with a population of approximately 100,000 people and another 150,000 living in the surrounding regional and remote areas. Public records list two maternity hospitals that service the area, one publicly funded and the other privately (Brodribb et al., 2007). Remoteness and population movement between the city and regional/remote areas could partly explain these observed patterns in birth rates and perinatal health identified for Toowoomba in this study. This would align with findings from a study using emerging hot spot analysis to explore adverse birth outcomes in Alberta, Canada, which found a spatially significant association between outcomes and environmental factors such as having less access to service centres (Nielsen et al., 2019). More research is needed to examine other location-based health determinants that could be driving the findings of this study. Such determinants could include clustering of demographically vulnerable groups, area-specific population changes over time, and the community's access to antenatal care services.

The types of services offered in any location are affected by local government policy, the availability of healthcare personnel, and access to resources (Eley & Baker, 2007). Increasing remoteness can present a notable geographical barrier to accessing health services by influencing decisions around healthcare engagement and selection of service providers (Ali et al., 2018). Internationally, studies into perinatal epidemiology have highlighted the importance of the location of healthcare providers during pregnancy. This has been found to be particularly important in identifying barriers to care such as travel time, number of appointments (more appointments required in high-risk pregnancies) and associated transport costs for low-income mothers (Bloch et al., 2018). Though reports exist into maternal access to care services in Australia (AIHW, 2017), none have focused specifically on the spatiotemporal distribution of antenatal care use in Queensland. In the current study, high proportions of public antenatal care providers were clustered in *Remote* and *Very remote* areas of Far North Queensland, northern Greater Brisbane, and Stradbroke Island, while significant hot spots for private providers were identified in more urban (*Inner regional* and *Major cities*) areas of southern Greater Brisbane and Cairns. In 2018–2019 there were 692 public hospitals across Australia, 26% of which were in *Major cities*, 58% in *Inner* and *Outer regional* areas, and 16% in *Remote* and *Very remote* areas (AIHW, 2020). Beyond bricks-and-mortar healthcare providers, mothers in remote Australia have access to mobile healthcare services through the public healthcare system. Public hospitals such as Normanton Hospital in remote north Queensland listed outreach services that included the Royal Flying Doctor Service, Mobile Women's Health Clinic and a Flying Obstetrician/Gynaecologist bringing antenatal care services to remote mothers (Baker & Butlini, 1991; Queensland, 2019a; RFDS, 2018).

Mothers receiving antenatal care in Queensland have the option to receive support from a public or private antenatal care provider. More antenatal care visits during pregnancy have been associated with better perinatal outcomes (Health, 2021). Current national guidelines recommend that a mother has their first antenatal visit within the first 10 weeks of pregnancy, and the number of appointments after this is determined based on the mother's needs (Health, 2021). State-specific research into antenatal care use, however, remains limited to assess the efficacy of antenatal care utilisation and perinatal outcomes. From 2008 to 2018, this study found Queensland mothers were more likely to select public antenatal care providers, with a preference for public midwifery practitioners. Although public antenatal care in Queensland works on a referral model based on a mother's location, ongoing preference for public over private antenatal care can be driven by associated benefits such as free access to specialist doctors, services and baby units, and the ability to choose a preferred hospital, obstetrician or midwife (Queensland, 2019b). Accessing private healthcare providers, on the other hand, can be restricted by a mother's access to private health insurance, her socio-economic status, personal choice, and her location. In 2017–2018, the ABS Patient Experience Survey showed that Australians most likely to report having private health insurance were the least socio-economically disadvantaged (78%) and located in *Major cities* (60%) (ABS, 2019b). This was supported by research focused on Queensland's Toowoomba region that found that mothers attending public hospitals were less likely to have private insurance and more likely to be socially and economically disadvantaged (Hegney et al., 2003).

The World Health Organization (WHO) recommends that all pregnant women should have at least eight contacts with a healthcare provider. This facilitates the uptake of preventative measures, timely detection of risky behaviours, reduces complications and addresses health inequalities (WHO, 2016). Proximity to maternal health facilities (public or private) is crucial for providing women with the resources to support positive perinatal health outcomes. A global review of antenatal care utilisation among pregnant women showed that distance from healthcare facilities, particularly when combined with lack of personal transportation or public transport options, led to a decrease in antenatal care utilisation and the frequency of services used (Ali et al., 2018). In this study, though mothers from Redland Islands had no significant trends in birth rates over time, they were part of a significant hot spot for high proportions of low birthweight and preterm births, and smoking during pregnancy. Redland Islands is a *Remote* area and was identified as part of a hot spot for high proportions of public antenatal care visits. However, the only identified island public hospital, the Marie Rose Centre (Dunwich), listed no maternity services and listed its closest main referral hospitals as Redland Hospital (24 km) and Princess Alexandra Hospital (50 km). Both hospitals were located on mainland Queensland, introducing restricted accessibility and additional travel costs (Queensland, 2017a). Socio-economic status can amplify the impact of geographical barriers on perinatal health due to the costs associated with gaining and maintaining personal transport and covering the cost of public transport use. The majority of areas with identified hot spots for high proportions of preterm and low birthweight births and smoking during pregnancy within this study were also areas categorised in the lowest quintile ranking of relative socio-economic advantage and disadvantage (ABS, 2018b). A spatial analysis of preterm births across Philadelphia found a similar relationship between region characteristics (majority race, poverty, and neighbourhood violence) and increased incidences of preterm births (Bloch, 2011).

Our findings on the spatial association between remoteness, antenatal care use and pregnancy outcomes across Queensland aligned with existing international studies using GIS within perinatal epidemiology. These are studies that have similarly found locations in developed countries where poor perinatal outcomes are occurring in areas where mothers are marginalised by geographical or socio-economic disadvantage. In the United States, lower socio-economic status and living in majority black communities were associated with low birthweight and preterm births in South Carolina (Runkle et al., 2022). In Philadelphia, neighbourhoods characterised by poverty, domestic assaults and gun violence were associated with a higher density of preterm births (Bloch, 2011). Across Baltimore, using density mapping and spatial regression, Galiatsatos et al. (2020) found that maternal smoking during pregnancy increased with tobacco store density and was more likely to be observed in neighbourhoods with lower neighbourhood education. Similar to our findings around the impacts of remoteness on outcomes and prenatal care, Bloch et al. (2018) used interpretative mapping to demonstrate the impact of travel time and bus fare costs on access to care for low-income mothers within urban Philadelphia. In British Columbia, Canada, a study looking into the impact of travel time found that similar vulnerabilities such as adolescent age, substance use and low socio-economic status were prevalent among mothers travelling further (≥60 minutes) for delivery. Furthermore, travel times ≥120 minutes were associated with increased stillbirths and maternal morbidity (Luke et al., 2022). Lower SES neighbourhoods across Southwestern Ontario were found to have higher rates of teenage pregnancies, with teenage mothers also found to be at a higher risk of depression, anxiety and smoking during pregnancy (Wong et al., 2020).

As global and national policy continues to encourage the improvement of maternal and infant health and welfare, the findings of this study highlight the importance of identifying small-area trends in perinatal health to inform future context-based policy and targeted environmental health research. In 1998, the WHO proposed a set of principles for perinatal care that encouraged the protection, promotion and support necessary for effective antenatal and postnatal care to support maternal and infant health. Among these principles was an emphasis on care being local and available as close to a woman's home as possible, and to include an efficient system of referral from primary to tertiary levels of care (Health, 2021). These principles are vital in the context of our study findings that identified significant clustering of low birthweight and preterm births, smoking during pregnancy, and antenatal care visits in Queensland.

Conclusion

There is significant spatial and temporal variation in Queensland's birth rates, perinatal health and antenatal care use. Using geographic information system (GIS) methods to analyse administrative health records allowed for the identification of small-area disparity over time and will support future informed exploration of the drivers of such localised patterns. Antenatal care providers, perinatal health professionals, and policy developers should consider the informative contribution of GIS analysis in perinatal health, particularly when identifying additional vulnerabilities within priority health groups.

Acknowledgements

We would like to thank the Statistical Services Branch at Queensland Health for their help accessing over a decade of perinatal data for analysis. The findings and views reported in this paper are those of the authors and should not be attributed to the Queensland State Health Department. We would also like to thank Katherine Green, senior consultant at Esri Australia, for her useful comments on the methodology used. Full human ethical approval (unconditional) was granted by the Australian National University Human Research Ethics Committee under protocol #2018/419, and access to Queensland perinatal data was granted by Queensland Health under the *Public Health Act 2005* (PHA), PHA 00419. We would also like to thank Associate Professor Robert Clark from the Australian National University (ANU) for helpful comments in preparing data for analysis. This project is part of a PhD project funded under an Australian Government Research Training Program Scholarship.

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