Investigating the factors associated with preterm birth using evidence from the Growing Up in New Zealand cohort: a retrospective geospatial study

SALATAS, Cristal <http://orcid.org/0000-0002-8069-4983>, HOBBS, Matthew, BLOOMFIELD, Frank H., ALEXANDER, Tanith and WALL, Clare R.

Health & Place 97 (2026) 103597

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

Investigating the factors associated with preterm birth using evidence from the Growing Up in New Zealand cohort: a retrospective geospatial study

Cristal Salatas [a], Matt Hobbs [d,e,f], Frank H. Bloomfield [a], Tanith Alexander [a,c], Clare R. Wall [b,*]

[a] Liggins Institute, University of Auckland, Auckland, New Zealand
[b] Department of Nutrition and Dietetics, Faculty of Medical and Health Sciences, University of Auckland, Auckland, New Zealand
[c] Neonatal Unit, Kidz First, Middlemore Hospital, Auckland, New Zealand
[d] Faculty of Health, Te Kaupeka Oranga, University of Canterbury, Te Whare Wānanga o Waitaha, Christchurch, Otautahi, New Zealand
[e] GeoHealth Laboratory, Te Taiwhenua o te Hauora, Geospatial Research Institute Toi Hangarau, University of Canterbury, Te Whare Wānanga o Waitaha, Christchurch, Otautahi, New Zealand
[f] College of Health, Wellbeing & Life Sciences, Sheffield Hallam University, Sheffield, United Kingdom

A R T I C L E I N F O

Keywords:
Preterm birth
Diet
Nutrition
Sociodemographic
Environment
New Zealand

A B S T R A C T

Background: Preterm birth (PTB) is a major public health concern with multifactorial causes. Modifiable factors, including nutrition and environmental influences, present opportunities for targeted intervention. This study examined associations between sociodemographic, nutritional, and environmental factors and PTB in a cohort of New Zealand (NZ) women.

Method: Data from 6822 mothers in the Growing Up in New Zealand cohort (2009–2010) were analysed to assess associations between sociodemographic characteristics, adherence to NZ food and nutrition guidelines, dietary patterns, micronutrient supplementation, and environmental factors (Healthy Location Index [HLI]) with PTB. Logistic and multilevel models were applied using RStudio.

Results: Of 6667 births, 436 (6.6 %) were preterm. Most sociodemographic factors, including maternal age, parity, BMI, ethnicity, and area-level deprivation, were not significantly associated with PTB. Non-adherence to breads and cereals Ministry of Health guidelines reduced odds (OR = 0.64; 95 % CI: 0.43, 0.91; p = 0.01), while a 'Junk' dietary pattern (OR = 1.28; 95 % CI: 1.07, 1.52; p = 0.007) and not taking iron supplements after the first trimester (OR = 1.46; 95 % CI: 1.06, 2.00; p = 0.02) increased odds. Residing in rural areas with moderate urban influence also increased odds (OR = 2.44; 95 % CI: 1.18, 4.66; p = 0.01). HLI demonstrated no significant associations.

Conclusions: Adherence to recommended food groups (breads and cereals), junk dietary patterns, low iron supplement intake after the first trimester, and rural residence with moderate urban influence were associated with increased PTB odds. Addressing maternal nutrition and geographic disparities could help mitigate this risk.

1. Introduction

Preterm birth (PTB), defined as babies born before 37 completed weeks of pregnancy, continue to be a significant global public health priority (WHO, 2023). PTB rates have been rising in high-income countries, despite the global rate remaining relatively stable at 9.8 % in 2010 to 9.9 % in 2020 (WHO, 2023). For example, the United States reports a 10.5 % PTB rate, which is higher than most other developed nations (Statista, 2023). In New Zealand, the most recent data from 2020 indicate that 7.9 % of babies were born preterm (Te Whatu Ora, 2022). The causes and risk factors for PTB often vary or remain unknown, further complicating efforts to implement preventive strategies (Khandre et al., 2022).

A growing body of evidence suggests that maternal nutrition may play a role in the aetiology of PTB. Studies have shown that a high-quality diet can reduce the risk of adverse birth outcomes, including PTB and low birthweight (Chia et al., 2019; Gete et al., 2019; Kibret et al., 2019; Salatas et al., 2025). Addressing maternal malnutrition in the preconception period can also significantly improve maternal health and reduce PTB risk (Raghavan et al., 2019; Stoody et al., 2019). New Zealand's Eating and Activity Guidelines translate the nutrient requirements presented by the National Health and Medical Research

* Corresponding author. Faculty of Medical and Health Sciences, University of Auckland, Auckland, New Zealand.
E-mail address: c.wall@auckland.ac.nz (C.R. Wall).

https://doi.org/10.1016/j.healthplace.2025.103597
Received 15 April 2025; Received in revised form 3 December 2025; Accepted 18 December 2025
Available online 23 December 2025

Council (NHMRC) into food servings (Ministry of Health, 2020). They advise on the number and size of servings of food from the four food groups, as well as the energy intake, food preparation, and nutrient requirements for pregnant and breastfeeding women (Ministry of Health, 2020). These guidelines also make recommendations on specific macronutrient composition (fat, protein, carbohydrates, and fibre) and micronutrients (minerals and vitamins) a mother should supplement during pregnancy and breastfeeding (Ministry of Health, 2020).

PTB is influenced by a complex interplay of factors extending beyond nutrition, including maternal social health, socioeconomic circumstances, and access to antenatal care (Dolatian et al., 2018; McHale et al., 2022; Richterman et al., 2020). Social determinants such as food insecurity and maternal stress are linked to increased PTB risk (Dolatian et al., 2018). Environmental determinants of health further contribute to this risk, with growing evidence highlighting the potential role of environmental stressors, such as the local food environment (Etzel, 2020; Willingham et al., 2020; Zar et al., 2019). Characteristics of the built environment , including urbanicity (Marek et al., 2020), are also well recognised as influential determinants of health (Hobbs et al., 2022). Together, these factors may affect birth outcomes through pathways including pollution exposure (Bekkar et al., 2020) or constrained access to nutritious food, such as food deserts (Tipton et al., 2020; Willingham et al., 2020).

Despite its importance, the role of maternal nutrition and wider factors, including the environment as modifiable risk factors, remains under-explored in New Zealand. This study aims to identify the nutritional, sociodemographic, and environmental factors associated with PTB in the Growing Up in New Zealand cohort, with a specific focus on whether the residential proximity to certain environmental and food outlets influences PTB risk.

2. Methods

2.1. Study design and population

This was a retrospective geospatial cohort study. The study population comprised participants from the large, ethnically diverse, longitudinal cohort study, Growing Up in New Zealand (GUiNZ) (www.growingup.co.nz). Inclusion criteria consisted of an estimated delivery date between April 25th, 2009, and March 25th, 2010, and living within a designated area in the North Island of New Zealand. The recruitment area was chosen to reflect a wide range of ethnic, sociodemographic, and environmental characteristics, ensuring the study population would be broadly representative of New Zealand's population (Morton et al., 2013, 2015). Ethical approval was obtained from the Ministry of Health Northern Y Regional Ethics Committee (NTY/08/06/055), and all participants gave written informed consent. The GUiNZ study's methodology and reporting align with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (von Elm et al., 2007).

2.2. Data

Maternal data (n = 6822) were sourced from the GUiNZ study and were collected through in-person interviews conducted by trained interviewers. The antenatal data collection wave was mainly conducted in the third trimester, and the six-week data collection wave was conducted six weeks post-partum using health records to confirm birth outcomes. Health and lifestyle status, nutritional factors, sociodemographic factors, and environmental factors were collected in the antenatal data collection wave and birth outcomes were collected in the six-week data collection wave (Table 1).

Health and lifestyle factors were selected a priori for inclusion as model covariates and for characterising the baseline cohort. All variables were a part of the antenatal data collection wave and include: 1) age (in years); 2) parity (firstborn, subsequent); 3) gestational weight

Table 1
Cohort sociodemographic, health and lifestyle characteristics, and birth outcomes.

Variable	Overall (n = 6667)[a]	Preterm (n = 436)[a]	Term (n = 6231)[a]
Age	30.1 ± 6	30.8 ± 6	30 ± 6
Ethnicity			
European	3644 (53.4)	247 (57)	3304 (53.1)
Māori	949 (13.9)	55 (12.7)	867 (13.9)
Pacific	996 (14.6)	54 (12.5)	914 (14.7)
Asian	1002 (14.7)	64 (14.8)	917 (14.7)
MELAA	144 (2.1)	<10	132 (2.1)
Other	95 (0.2)	<10	88 (0.2)
BMI	25.4 ± 5.9	26 ± 6	25.3 ± 5.9
Relationship Status			
No relationship	334 (5.4)	30 (7.8)	293 (5.2)
Dating, not cohabitating	259 (4.2)	16 (4.2)	236 (4.2)
Cohabiting	1727 (27.9)	100 (26)	1576 (27.9)
Married or civil union	3866 (62.5)	238 (62)	3535 (62.7)
Parity			
First born	2865 (41.9)	186 (42.7)	2577 (41.4)
Subsequent	3977 (58.1)	250 (57.3)	3652 (58.6)
Pre-Pregnancy Health[b]			
Poor	152 (2.2)	<10	137 (2.2)
Fair	548 (8)	45 (10.3)	489 (7.8)
Good	2324 (33.9)	153 (35.1)	2113 (33.9)
Very Good	2412 (35.2)	136 (31.2)	2207 (35.4)
Excellent	1399 (20.4)	92 (21.1)	1277 (20.5)
Unknown	14 (0.2)	<10	<10
Gestational Weight Gain[b]			
Put on ≥ 5 kg so far	5408 (87.2)	325 (84.6)	4941 (87.4)
Put on weight <5 kg	445 (7.2)	26 (6.8)	408 (7.2)
Stayed the same weight	53 (0.9)	<10	45 (0.8)
Lost weight, < 5 kg	99 (1.6)	15 (3.9)	83 (1.5)
Lost weight, ≥ 5 kg	76 (1.2)	<10	70 (1.2)
Unknown	121 (2)	<10	109 (1.9)
Smoking			
Continued smoking	643 (10.4)	52 (13.6)	571 (10.1)
Stopped smoking	609 (9.9)	32 (8.4)	563 (10)
Non-smoker	4929 (79.7)	297 (78)	4505 (79.9)
Alcohol			
Any drinking during pregnancy	1929 (28.2)	103 (23.6)	1772 (28.5)
Stopped drinking	2948 (43.2)	202 (46.3)	2676 (43)
Non-drinker	1953 (28.6)	131 (30)	1769 (28.5)
Education			
No sec school qualification	489 (7.2)	35 (8)	446 (7.2)
Sec school/NCEA 1-4	1625 (23.8)	104 (23.9)	1483 (23.8)
Diploma/trade cert/ NCEA 5-6	2094 (30.7)	136 (31.2)	1903 (30.6)
Bachelor's degree	1552 (22.7)	104 (23.9)	1401 (22.5)
Higher degree	1070 (15.7)	57 (13.1)	986 (15.9)
Deprivation Tertiles			
Low (1–3)	1708 (24.9)	111 (25.5)	1556 (25)
Medium (4–7)	2504 (36.6)	175 (40.1)	2265 (36.4)
High (8–10)	2635 (38.5)	150 (34.4)	2408 (38.7)
Urban/Rural Classification			
Main urban area	5847 (85.4)	362 (83)	5343 (85.7)
Satellite urban area	297 (4.3)	14 (3.2)	268 (4.3)
Independent urban area	232 (3.4)	22 (5)	203 (3.3)
Rural area with high urban influence	103 (1.5)	<10	95 (1.5)
Rural area with moderate urban influence	144 (2.1)	15 (3.4)	122 (2)
Rural area with low urban influence	195 (2.8)	17 (3.9)	172 (2.8)
Highly rural/remote area	31 (0.5)	<10	28 (0.4)
Gender			
Male	3530 (51.5)	227 (52.1)	3207 (51.5)
Female	3319 (48.5)	209 (47.9)	3024 (48.5)
Term			
Preterm	436 (6.6)	436 (100)	0
Term	6231 (93.4)	0	6231 (100)
Birthweight	3482 ± 584	2423 ± 716	3547 ± 496
Micronutrient Intake			
Folic acid taken pre-pregnancy			

(continued on next page)

Table 1 (*continued*)

Variable	Overall (n = 6667)[a]	Preterm (n = 436)[a]	Term (n = 6231)[a]
Yes	2407 (38.8)	162 (42.2)	4504 (79.6)
No	3790 (61.1)	221 (57.6)	1149 (20.3)
Unknown	<10	<10	<10
Folic acid taken during 1st trimester			
Yes	4957 (79.9)	329 (85.7)	4504 (79.6)
No	1241 (20)	54 (14.1)	1149 (20.3)
Unknown	<10	<10	<10
Folic acid taken after1st trimester			
Yes	3432 (55.3)	242 (63)	3098 (54.8)
No	2764 (44.6)	142 (37)	2552 (45.1)
Unknown	<10	–	<10
Iron taken pre-pregnancy			
Yes	1407 (22.7)	82 (21.4)	1297 (22.9)
No	4788 (77.2)	301 (78.4)	4353 (77)
Unknown	<10	<10	<10
Iron taken during1st trimester			
Yes	2729 (44)	194 (50.5)	2462 (43.5)
No	3469 (55.9)	188 (49)	3192 (56.4)
Unknown	<10	<10	<10
Iron taken after1st trimester			
Yes	3998 (64.5)	247 (56.7)	3639 (64.3)
No	2197 (35.4)	135 (31)	2012 (35.6)
Unknown	<10	<10	<10
Vitamins/minerals taken pre-pregnancy			
Yes	1878 (30.3)	123 (32)	1714 (30.3)
No	4321 (69.7)	261 (68)	3939 (69.6)
Unknown	<10	–	<10
Vitamins/minerals taken during1st trimester			
Yes	3103 (50)	209 (54.4)	2823 (49.9)
No	3096 (49.9)	174 (45.3)	2831 (50.1)
Unknown	<10	<10	<10
Vitamins/minerals taken after1st trimester			
Yes	3240 (52.2)	226 (58.9)	2939 (52)
No	2960 (47.7)	158 (41.1)	2715 (48)
Unknown	<10	–	<10
Adherence to MoH food groups			
Fruit and vegetables			
Yes	1532 (24.7)	88 (22.9)	1403 (24.8)
No	4670 (75.3)	296 (77.1)	4253 (75.2)
Breads and cereals			
Yes	1696 (27.3)	122 (31.8)	1533 (27.1)
No	4506 (72.7)	262 (68.2)	4123 (72.9)
Milk products			
Yes	3601 (58.1)	233 (60.7)	3278 (58)
No	2601 (41.9)	151 (39.3)	2378 (42)
Meats			
Yes	1406 (22.7)	91 (23.7)	1280 (22.6)
No	4794 (77.3)	293 (76.3)	4374 (77.4)

[a] Data are presented as n (%) or mean ± SD.

[b] Self-reported at time of antenatal interview. cert: certificate; MELAA: Middle Eastern/Latin American/African; NCEA: national certificate of educational achievement; sec: secondary.

gain (put on 5 kg or more through to lost weight, 5 kg or more); 4) pre-pregnancy BMI (calculated using self-reported pre-pregnancy weight and height [in kg/m^2]); 5) pre-pregnancy self-rating of health status (rating of poor to excellent); 6) smoking status during pregnancy (continued smoking during pregnancy, stopped smoking during pregnancy, non-smoker); 7) alcohol status during pregnancy (continued drinking during pregnancy, stopped drinking during pregnancy, non-drinker); 8) relationship status with the father of the baby; 9) high blood pressure/heart disease (before and/or during pregnancy); 10) anaemia (before and/or during pregnancy), and 11) diabetes (before and/or during pregnancy). These factors were either modeled as predictors or reported as baseline characteristics, with each variable's inclusion justified by prior literature as relevant to maternal and perinatal outcomes.

Nutritional factors and dietary patterns include: 1) dietary intake assessed using a semi-quantitative 44-item food frequency questionnaire (FFQ) that evaluated consumption over the previous four weeks during the third trimester of pregnancy. Dietary patterns were created using a principal components analysis (PCA) and described in detail elsewhere (Supplementary Fig. 1) (Morton et al., 2014; Wall et al., 2016); 2) self-reported micronutrient supplementation before and during pregnancy (folic acid, iron, and vitamin/mineral intake); and 3) self-reported adherence to the Ministry of Health (MoH) food group recommendations (bread/cereals, fruits/vegetables, meats, dairy) (Ministry of Health, 2020). Adherence was measured via an FFQ to determine the frequency of consumption of the four food groups, as recommended by the MoH Food and Nutrition Guidelines for Healthy Pregnant and Breastfeeding Women (FNGPB) (Ministry of Health, 2008).

Sociodemographic factors include: 1) self-reported ethnicity, which was categorised into six groups: European; Māori; Pacific Peoples; Asian; Middle Eastern/Latin American/African (MELAA), and Other based on coding criteria from Statistics New Zealand (StatsNZ, 2004); 2) area-level deprivation was assessed using the New Zealand Deprivation Index (NZDep06) score (Salmond et al., 2007), which is grouped into quantiles ranging from 1 (low deprivation) to 10 (high deprivation) and includes nine socioeconomic indicators: home ownership; single-parent households; income; benefits; education; employment; car and telephone access, and household crowding; 3) highest education level obtained (no secondary schooling through to higher degree); and 4) urban/rural domicile classification as categorised by the GUiNZ data team (urban through to highly remote/rural area), which was determined by geo-coding from address data according to Statistics NZ categories (Morton et al., 2015; StatsNZ, 2006).

Birth outcomes include: 1) gestational age at birth (in weeks) and term (preterm [<37 gestational weeks (GW)], term [37–41 GW], and post-term [>41 GW]); 2) sex of the baby (boy, girl); and 3) birth weight (in grams). All were collected by mapping the information from GUiNZ's six-week data collection wave to the district health boards (DHB) health records using the participants' national health identifier.

Environmental factors include: the Healthy Location Index (HLI), a composite, area-based measure developed in New Zealand to characterise neighbourhoods according to their combined access to multiple health-promoting ("goods") and health-constraining ("bads") environmental features. The HLI was constructed by grouping environmental "goods" and "bads" into three categories based on decile rankings: best accessibility (deciles 1–3), moderate accessibility (deciles 4–7), and worst accessibility (deciles 8–10). For "goods," category one represents the most health-promoting environments, while for "bads," category one indicates the most health-constraining environments. Combining these categories produced nine possible combinations of "goods" and "bads," resulting in a composite HLI assigned at the meshblock level across New Zealand (Supplementary Fig. 2). The environmental features included in the HLI comprise various food outlets (supermarkets [n = 571], fast food outlets [n = 754], takeaways [n = 2428], dairy/convenience stores [n = 2130], and fruit and vegetable retailers [n = 223]), recreational spaces (green and blue spaces [n = 1189]), and alcohol and vaping outlets (n = 12,695). The source of the environmental features data for this study is the University of Canterbury GeoHealth Laboratory (canterbury.ac.nz), based on the HLI dataset (Marek et al., 2021).

2.3. Outcomes

Our study had one binary outcome of interest: PTB (yes/no), defined as birth before 37 completed weeks of pregnancy or not (WHO, 2023).

2.4. Statistical analyses

Maternal sociodemographic factors, health and lifestyle status, birth outcomes, and nutritional status before and during pregnancy are summarised as frequencies (%) for categorical variables and means (SD) for continuous variables (Table 1). Complying with GUiNZ reporting policy, variables with fewer than 10 data points (<10) are reported as "<10".

We employed several logistic regression models to assess the association between PTB and sociodemographic factors, maternal characteristics, food groups, dietary patterns, micronutrient supplementation, and the proximity of environmental factors to a mother's residence. Models were adjusted for potential confounders (parity, ethnicity, maternal age, education, BMI, anaemia, high blood pressure, and diabetes) to account for any potential influence on the outcome of PTB. Adherence to MoH food group recommendations, micronutrient supplement intake before and during pregnancy, and dietary patterns were included in the adjusted model. The inclusion of variables in adjusted models was based on their association with PTB in multivariate models or those frequently associated with PTB in existing literature (Al-Naseem et al., 2021; Delker et al., 2022; Finkelstein et al., 2020; Li et al., 2023) to ensure that our regression models appropriately adjust for key factors potentially influencing the associations under investigation.

To address the clustering of observations within geographical areas, we specified a cross-classified multilevel logistic regression model (MLM) to account for the non-nested clustering of individuals within two geographical classifications: area-level deprivation tertile and urban/rural classification. Individuals (level 1) belonged simultaneously to one deprivation tertile group and one urban/rural group (both level 2 classifications) rather than a strict hierarchy. This approach improves model accuracy by accounting for clustering effects and between-group variation that could bias estimates in standard logistic regression. We included fixed effects for nutritional, sociodemographic, and environmental factors to assess their association with PTB, and added random intercepts for deprivation tertile and urban/rural classification to account for clustering and unmeasured differences between these groups. Including these random effects allowed us to capture context-specific variability in PTB across both classification types.

Results are reported as frequency (%), odds ratios (OR) or adjusted odds ratios (aOR), and 95 % confidence intervals (CI). A p-value of <0.05 was considered statistically significant. Multicollinearity was assessed using Variable Inflation Factor (VIF) and values < 5 suggest low multicollinearity (Supplementary Table 1). Statistical analysis was performed utilising R software (R Core Team, 2023).

2.5. Geospatial analysis

For spatial analysis of the environmental factors, we used meshblocks, the smallest administrative units reported by Stats NZ (StatsNZ, 2019). Accessibility to the environmental factors was measured using road network distances from the 2018 population-weighted centroids of each meshblock (Beere, 2016) via ArcGIS Pro v2.4 (ESRI, 2019). For green and blue spaces, proximity was measured using Euclidean distance from all points within a 50×50 m grid rather than the nearest entrance, as these spaces are area-based, often lack clear entry points, and may provide health benefits through visibility and accessibility. Full details regarding the identification and assessment of environmental features, including the geocoding methods, have been described extensively elsewhere (Marek et al., 2021). The data management team at GUiNZ linked the provided spatial environmental data (with meshblock IDs) to participants' residential addresses at the time of the interview and their maternal GUiNZ identifier. The resulting output file included a numeric length variable representing the distance of each environmental factor to the corresponding meshblock ID for use in the regression models.

3. Results

3.1. Descriptive statistics

Characteristics of women in the GUiNZ cohort have been published elsewhere (Morton et al., 2013). The sociodemographic, birth outcomes, health status, and lifestyle characteristics of the women included in our study are demonstrated in Table 1. Our cohort includes 6667 women with a mean age of 30 years (SD 6). The majority identified as European (53.4 %), followed by Asian (14.7 %), Pacific (14.6 %), Māori (13.9 %), and smaller proportions from MELAA and other ethnicities. Most participants were married or in a civil union (62.5 %), and 41.9 % were first-time mothers. Educational attainment was high, with 38.4 % holding a bachelor's degree or higher, while 31 % reported trade certifications or diplomas. Area-level deprivation was distributed as 24.9 %, 36.6 %, and 38.5 % in low, medium, and high deprivation tertile, respectively. The majority resided in main urban areas (85.4 %).

Regarding health and lifestyle characteristics, 79.7 % of women were non-smokers, while 10.4 % continued smoking during pregnancy. Alcohol use was reported by 28.2 % during pregnancy, although 43.2 % reported stopping drinking during pregnancy. The mean pre-pregnancy BMI was 25.4 (SD 5.9), and over half (55.6 %) rated their pre-pregnancy health as very good or excellent. Most women (87.2 %) reported gaining 5 kg or more during pregnancy. PTB accounted for 6.6 % of deliveries, with a mean birthweight of 3482 g (SD 584).

Overall, the cohort had low adherence to dietary guidelines and micronutrient supplement intake across participants (Lawrence et al., 2022), with some differences between preterm and term pregnancies. Adherence to MoH food group guidelines was low, with only 24.7 % meeting recommendations for fruits and vegetables and 27.3 % for breads and cereals, though slightly higher adherence was seen among preterm pregnancies. Only 38.8 % of participants took folic acid supplements pre-pregnancy, which increased to 79.9 % during the first trimester but dropped to 55.3 % after the first trimester. Similarly, iron supplement intake increased from 22.7 % pre-pregnancy to 64.5 % after the first trimester. Multicollinearity was assessed using VIF; all values were below 5, suggesting acceptable tolerance (Supplementary Table 1).

3.2. Multiple logistic regression models examining associations of variables with PTB

We used four models to examine associations with PTB, with one model designated as exploratory (Supplementary Table 2) because it exceeds the recommended events per predictor/variable (EPP/EPV) guidance of 10–20 events per predictor (Ogundimu et al., 2016; Riley et al., 2019). The first logistic regression model included dietary patterns, supplementation, and PTB with adjustments for parity, BMI, anaemia, high blood pressure, diabetes, ethnicity, age, and education, as presented in (Table 2). Models 2 and 3 (the latter exploratory) sequentially added sociodemographic and environmental variables, respectively. Finally, a multilevel model (model 4) clustered by urban/rural classification incorporated all variables.

3.3. Nutritional factors

Among adherence to MoH food group recommendations, women who did not follow the breads and cereals guidelines had significantly reduced odds of PTB compared to those who adhered to the recommendations (reference level) across all models (Table 2 and Supplementary Table 2). In contrast, adherence to recommendations for other food groups, including fruit and vegetables, dairy products, and meats, was not significantly associated with PTB (all $p \geq 0.05$) in any model.

For dietary patterns, higher scores on the 'Junk' pattern were significantly associated with 15–28 % increased odds of PTB across all models (Table 2 and Supplementary Table 2). The health-conscious, traditional/white, and fusion/protein patterns were not significantly associated with PTB in any model (all $p > 0.05$).

Micronutrient supplement intake before and during pregnancy showed varied associations with PTB. Women who did not take folic acid during the first trimester had significantly reduced odds of PTB compared to those who did (reference level), although this was statistically significant in models 1 and 2 only (Table 2). Women who did not take iron supplements before pregnancy or after the first trimester had 43–49 % increased odds of PTB compared to those who took iron

Table 2
Logistic regression models (models 1–2) and multilevel model (model 4) results for the association of sociodemographic, nutritional, and environmental factors with preterm birth.

Variable	Model 1 OR (95 % CI)	Model 1 aOR (95 % CI)[a]	Model 2 OR (95 % CI)	Model 4 OR (95 % CI)
Health and lifestyle				
Age			1.02 (0.99, 1.04)	1.00 (0.97, 1.04)
Parity				
First born			REF	REF
Subsequent			0.79 (0.60, 1.03)	0.85 (0.61, 1.17)
BMI			1.01 (0.99, 1.03)	1.00 (0.97, 1.02)
Anaemia				
Never			REF	REF
Before pregnancy			0.91 (0.64, 1.27)	0.75 (0.43, 1.14)
Before and during pregnancy			0.87 (0.52, 1.38)	0.84 (0.49, 1.47)
During pregnancy			1.31 (0.74, 2.17)	1.34 (0.72, 2.49)
High Blood Pressure				
Never			REF	REF
Before pregnancy			1.55 (0.95, 2.44)	1.52 (0.86, 2.69)
Before and during pregnancy			2.33 (1.15, 4.34)*	2.32 (0.99, 5.39)
During pregnancy			1.99 (0.91, 3.92)	2.26 (0.99, 5.15)
Diabetes				
Never			REF	REF
Before pregnancy			0.55 (0.06, 2.12)	0.57 (0.07, 4.32)
Before and during pregnancy			2.83 (1.28, 5.69)*	3.00 (1.16, 7.71)*
During pregnancy			1.06 (0.39, 2.38)	1.54 (0.58, 4.10)
Smoking/Alcohol				
Non-smoker/Non-drinker			REF	REF
Continued smoking during pregnancy			1.62 (1.01, 2.54)*	1.13 (0.61, 2.06)
Stopped smoking during pregnancy			0.90 (0.55, 1.42)	0.85 (0.48, 1.49)
Any drinking during pregnancy			0.80 (0.56, 1.16)	0.82 (0.53, 1.27)
Stopped drinking during pregnancy			0.98 (0.72, 1.35)	0.97 (0.66, 1.43)
Deprivation Tertiles				
Low (1–3)			REF	Cluster variable
Medium (4–7)			1.01 (0.75, 1.36)	
High (8–10)			0.93 (0.65, 1.33)	
Ethnicity				
European			REF	REF
Māori			0.79 (0.50, 1.23)	0.72 (0.41, 1.27)
Pacific			0.96 (0.56, 1.62)	1.27 (0.68, 2.35)
Asian			1.15 (0.74, 1.77)	0.99 (0.56, 1.75)
MELAA			1.14 (0.45, 2.43)	1.41 (0.43, 4.68)
Other			3.21 (0.33, 14.99)	3.54 (0.39, 4.20)
Education				
Sec. school/NCEA 1-4			REF	REF
Diploma/Trade cert/NCEA 5-6			0.87 (0.62, 1.22)	0.83 (0.55, 1.23)
Bachelor's degree			0.91 (0.64, 1.31)	0.80 (0.52, 1.22)
Higher degree			0.68 (0.44, 1.04)	1.16 (0.25, 1.46)
No sec. school qualification			0.77 (0.38, 1.43)	0.63 (0.39, 1.03)
Urban/rural classification				Cluster variable
Main urban area			REF	
Satellite urban area			0.70 (0.34, 1.31)	
Independent urban area			1.55 (0.86, 2.64)	
Rural area with high urban influence			0.83 (0.27, 1.98)	
Rural area with moderate urban influence			2.10 (1.13, 3.65)*	
Rural area with low urban influence			1.14 (0.56, 2.09)	
Highly rural/remote area			0.97 (0.11, 3.80)	
Adherence to MoH food groups				
Adherence to food groups	REF	REF	REF	REF
Fruit and vegetables (non-adherence)	1.01 (0.72, 1.41)	1.03 (0.74, 1.44)	1.03 (0.74, 1.44)	0.85 (0.57, 1.27)
Breads and cereals (non-adherence)	0.71 (0.52, 0.96)*	0.71 (0.52, 0.98)*	0.71 (0.52, 0.98)*	0.62 (0.43, 0.91)**
Milk products (non-adherence)	0.85 (0.65, 1.11)	0.84 (0.64, 1.11)	0.86 (0.65, 1.12)	1.00 (0.72, 1.39)
Meats (non-adherence)	0.97 (0.66, 1.4)	0.96 (0.67, 1.41)	0.97 (0.67, 1.43)	1.21 (0.73, 2.02)
Micronutrient intake before and during pregnancy				
Intake of micronutrients	REF	REF	REF	REF
Folic acid not taken pre-pregnancy	0.87 (0.65, 1.17)	0.89 (0.66, 1.21)	0.92 (0.67, 1.25)	0.97 (0.67, 1.39)
Folic acid not taken during1st trimester	0.55 (0.35, 0.87)*	0.59 (0.37, 0.92)*	0.58 (0.36, 0.92)*	0.66 (0.37, 1.21)
Folic acid not taken after1st trimester	0.77 (0.56, 1.05)	0.80 (0.59, 1.09)	0.78 (0.57, 1.06)	0.73 (0.5, 1.06)
Iron not taken pre-pregnancy	1.48 (1.02, 2.14)*	1.48 (1.03, 2.16)*	1.49 (1.03, 2.16)*	1.52 (0.98, 2.35)
Iron not taken during1st trimester	0.70 (0.51, 0.95)	0.70 (0.51, 0.96)	0.70 (0.51, 0.97)	0.76 (0.52, 1.11)
Iron not taken after1st trimester	1.46 (1.06, 2.00)*	1.44 (1.04, 1.99)*	1.43 (1.03, 1.98)*	1.47 (1.00, 2.16)*
Vitamins/minerals not taken pre-pregnancy	0.88 (0.61, 1.25)	0.85 (0.60, 1.21)	0.85 (0.60, 1.21)	0.82 (0.54, 1.24)
Vitamins/minerals not taken during1st trimester	1.43 (0.98, 2.07)	1.48 (1.02, 2.15)*	1.48 (1.02, 2.15)*	1.03 (0.67, 1.6)
Vitamins/minerals not taken after1st trimester	0.77 (0.53, 1.11)	0.74 (0.51, 1.07)	0.75 (0.51, 1.09)	1.05 (0.67, 1.64)
Dietary patterns				
Junk	1.15 (1.02, 1.30)**	1.17 (1.03, 1.32)**	1.16 (1.02, 1.31)*	1.28 (1.07, 1.52)**
Health conscious	0.87 (0.75, 1.02)	0.90 (0.77, 1.06)	0.92 (0.78, 1.08)	0.88 (0.72, 1.08)
Traditional/white	0.97 (0.84, 1.12)	0.98 (0.84, 1.15)	0.97 (0.83, 1.13)	0.94 (0.77, 1.14)
Fusion/protein	0.92 (0.79, 1.08)	0.90 (0.76, 1.06)	0.91 (0.77, 1.07)	0.79 (0.62, 1.01)
HLI				
2-3				REF
1-1				0.96 (0.6, 1.55)
1-2				0.97 (0.62, 1.51)
1-3				0.91 (0.27, 3.05)
2-1				0.84 (0.48, 1.46)

(continued on next page)

Table 2 (*continued*)

Variable	Model 1 OR (95 % CI)	Model 1 aOR (95 % CI)[a]	Model 2 OR (95 % CI)	Model 4 OR (95 % CI)
2-2				1.26 (0.71, 2.23)
3-1				0.99 (0.23, 4.32)
3-2				1.09 (0.62, 1.92)
3-3				0.80 (0.51, 1.27)

[a] Adjusted (a) for parity, body mass index (BMI), anaemia, high blood pressure, diabetes, ethnicity, age, and education. Odds ratios (OR) and 95 % confidence intervals (CI). cert: certificate; HLI: Healthy Location Index (Categories for environmental 'goods' rank neighbourhoods from 1 (most health-promoting) to 3 (least health-promoting) based on access to beneficial features, while categories for environmental 'bads' rank from 1 (most health-constraining) to 3 (least health-constraining) according to exposure to detrimental features. Combined categories indicate the joint influence of both environmental 'goods' and 'bads', with 1–3 representing high-promoting/low-constraining and 3-1 indicating low-promoting/high-constraining environments); MELAA: Middle Eastern/Latin American/African; MoH: Ministry of Health; NCEA: national certificate of educational achievement; sec: secondary; REF: reference; $^{*}p < 0.05$; $^{**}p \leq 0.01$; $^{***}p \leq 0.001$; Model 1: Association of nutritional factors and preterm birth, with and without adjustments for maternal sociodemographic, health, and lifestyle factors[1]; Model 2: Association of sociodemographic and nutritional factors and preterm birth; Model 4: Multilevel model for the clustering of observations in each urban/rural classification.

supplements during both of those periods (reference level), and this was statistically significant in models 1 and 2 for iron take before pregnancy and across all models for iron taken after the first trimester (Table 2). Women who did not take vitamins and minerals during the first trimester were associated with 48 % increased odds of PTB compared to those who took vitamins/minerals in the first trimester (reference level), although this was significant in models 1 and 2 only (Table 2). Intake of other micronutrient supplements, including folic acid supplements outside the first trimester and vitamins or minerals before pregnancy and after the first trimester, was not significantly associated with PTB (all $p \geq 0.05$).

3.4. Sociodemographic factors

Sociodemographic, health, and lifestyle characteristics revealed that women with high blood pressure or diabetes before and during pregnancy had increased odds of PTB compared to those who have never had high blood pressure or diabetes (reference level), and this was statistically significant in model 2 for both diabetes and high blood pressure, as well as exploratory model 3 and model 4 for diabetes (Table 2 and Supplementary Table 2). Women who continued smoking during pregnancy had significantly higher odds of PTB compared to those who didn't smoke (reference level), although this was statistically significant in model 2 only (Table 2). In contrast, women who stopped smoking during pregnancy showed no significant association with PTB in all models. Alcohol consumption during pregnancy, whether continued or discontinued, was not significantly associated with PTB in any model. Similarly, age, parity, BMI, anaemia, area-level deprivation, education, and ethnicity were not significant predictors across all models (all $p > 0.05$).

3.5. Environmental factors

The women living in rural areas with moderate urban influence had significantly higher odds of PTB compared to those residing in main urban areas (reference level) in all models in which the variable was measured (Table 2 and Supplementary Table 2). No significant associations were observed for other urban/rural classifications in all models (all $p > 0.05$).

Mother's residential proximity to all environmental features (HLI) was not significantly associated with PTB in exploratory model 3 and model 4 ($p > 0.05$ for all) (Table 2 and Supplementary Table 2).

4. Discussion

This retrospective geospatial cohort study utilised data from the GUiNZ longitudinal cohort study to examine the relationship between sociodemographic, nutritional, and environmental factors and PTB in 6667 pregnant women (2009–2010). The PTB rate in our study cohort was 6.6 %, which is lower than the national rate of 7.5 % for that period (Te Whatu Ora, 2022). Although the cohort overall was representative of the New Zealand population (Morton et al., 2015), this lower PTB rate may reflect that the sample is not a national cohort, or possible selection bias, women agreeing to participate may have been at lower risk of PTB, or participation in the study may have positively influenced behaviours during pregnancy. Our findings show that despite a comprehensive analysis, most variables demonstrated no statistically significant associations, underscoring the multifactorial nature of PTB and the challenges of identifying clear risk factors, such as the modifiable and non-modifiable factors that may offer key insights for targeted interventions. However, several important findings were identified in this study.

Among dietary factors, non-adherence to breads and cereals guidelines was consistently associated with reduced odds of PTB. Adherence to MoH food group recommendations (Ministry of Health, 2008, 2020) was low overall, particularly for fruits, vegetables, breads, and cereals. Preterm pregnancies demonstrated modestly higher adherence to breads, cereals, and milk products. This unexpected finding may suggest potential nuances in the relationship between carbohydrate intake and pregnancy outcomes, or it could be due to residual or unmeasured confounding, such as women at higher risk for PTB being more proactive with recommendations and antenatal visits, warranting further exploration into the role of dietary quality and composition. It may also be a proxy for consuming more bread due to insufficient funds for higher-cost food such as protein. Similarly, higher adherence to the 'Junk' dietary pattern was significantly linked to increased odds of PTB, reinforcing the established association between poor diet quality and adverse pregnancy outcomes. These findings align with prior research emphasising the detrimental impact of processed and nutrient-poor diets during pregnancy and highlight the potential importance of dietary quality in influencing birth outcomes (Kibret et al., 2019).

Micronutrient supplementation demonstrated mixed results. We found that folic acid, iron, and vitamin/mineral supplement intake increased during pregnancy, peaking in the first and second trimesters. The preterm pregnancies demonstrated a higher intake of folic acid supplements and lower iron and vitamin/mineral supplements, which may indicate an increased focus on folic acid supplementation due to risk awareness or medical advice. While folic acid supplement intake during pregnancy, typically recommended for neural tube defect prevention (Lassi et al., 2013), was not associated with PTB, the lack of iron supplementation pre-pregnancy and after the first trimester was linked to an increased risk.

In New Zealand, iron supplementation is only recommended if screening at the first antenatal visit and around 28 weeks' gestation reveals iron-deficiency anaemia (Te Whatu Ora, 2023). This screening-based approach may fail to identify women with suboptimal but non-anaemic iron levels, who may still be at increased risk for adverse pregnancy outcomes (Al-Naseem et al., 2021). Moreover, limiting screening to these two visits fails to capture and treat potential iron-deficiency anaemia that may have occurred before pregnancy or between the first trimester and the 28-week visit (Calje and Skinner, 2017), which could explain our findings. The demand for iron increases during pregnancy as maternal blood volume expands by 35–40 % to support fetal growth (Gambling et al., 2011; Picciano, 2003), imposing a net iron cost of 600–800 mg on maternal stores (Burke et al., 2014; Gambling et al., 2011; Picciano, 2003). Iron sufficiency appears to play a crucial role in reducing PTB risk, aligning with studies that highlight its importance for birth outcomes (Finkelstein et al., 2020, 2024; Peña-Rosas et al., 2015). Previous research has demonstrated that women with pregnancy complications are more likely to seek antenatal care earlier in pregnancy and more frequently compared to their counterparts (Abuosi et al., 2024; Nesro et al., 2021). Further research is needed to explore whether earlier, second-trimester, or more comprehensive iron supplementation strategies could improve pregnancy outcomes, particularly for women who fall within the grey zone of marginal iron sufficiency but do not meet the threshold for clinical intervention, and those who develop iron deficiency during the second trimester. However, a key limitation is that the GUiNZ interviewers did not ask participants whether they had been screened for, or diagnosed with, iron deficiency, nor did they explore the reasons why some women took iron supplements while others did not. Additionally, not all pregnant women in New Zealand attend antenatal screening, and data on overall attendance is not readily available. As a result, our findings must be interpreted cautiously, as we cannot fully account for the underlying factors influencing iron supplementation decisions or potential undiagnosed iron deficiency.

Sociodemographic variables, including age, parity, BMI, ethnicity, and area-level deprivation, were largely not significant predictors of PTB. Expectedly, high blood pressure and diabetes before and during pregnancy were significant predictors, agreeing with previous evidence (Delker et al., 2022; Li et al., 2023). We observed a marginal association between higher education and increased odds of PTB. This aligns with previous research suggesting that highly educated women may experience greater stress due to increased work-related demands (Solomon et al., 2022). While unexpected, this finding may reflect unmeasured or residual confounding factors, such as advanced maternal age or occupation-related stress, both of which have been linked to a higher risk of PTB (Esposito et al., 2022; Leader et al., 2018; Lilliecreutz et al., 2016). Rural residence with moderate urban influence was the only significant residential region associated with increased odds of PTB, suggesting that spatial variations and geographic disparities in access to healthcare or other critical resources may contribute to adverse outcomes, which has been demonstrated in previous literature (Bloch, 2011; Jankowska et al., 2019; Ogneva-Himmelberger et al., 2015; Root et al., 2020; South et al., 2012). This may also support previous New Zealand-based research, which showed poorer health outcomes across several measures in children and adults in more semi-urban areas (Marek et al., 2020).

The lack of significant associations for other factors, such as area-level deprivation, alcohol consumption, and smoking (except for one model demonstrating its significance), contrasts with some prior research, which has identified these variables as key contributors to adverse pregnancy outcomes (Dixon et al., 2020; Wall et al., 2016; Watson and McDonald, 2010). This discrepancy may reflect differences in study design, cohort characteristics and size, potential underreporting, or other confounders, such as the consistent finding of increased odds of PTB in rural areas with moderate urban influence. For instance, contrary to expectations, a mothers HLI (proximity to environmental features such as food outlets, alcohol/vape outlets, physical activity centres, and green/bluespaces) showed no significant associations. However, previous evidence has highlighted null findings (Wilkins et al., 2019), and it may be that other factors have a more measurable impact during pregnancy in this context. It also highlights the complexity of environmental determinants, suggesting that individual-level behaviours may affect their influence on PTB. In addition, we only accounted for physical access, which does not consider the quality of the environment (Hobbs et al., 2017) or indeed the mother's behaviour or usage of food outlets (Liu et al., 2022, 2023) or other environmental features within the HLI that are near their home residence, which in this study was used as a proxy for exposure (Campbell et al., 2021). Finally, rural areas with moderate urban influence may be exposed to geographic disparities in access to healthcare services, such as limited access to antenatal care, specialised maternal care, or emergency obstetric services (Marek et al., 2020).

Our study has several strengths. The cohort comprised an ethnically diverse and large population representative of pregnant women in NZ. Additionally, our models accounted for potential confounders, enhancing the robustness of our findings. Importantly, our results highlight actionable opportunities to improve maternal nutrition and address geographic inequities to reduce PTB risk. Interventions promoting healthier dietary patterns and encouraging appropriate iron supplementation, particularly among vulnerable populations, could have a meaningful impact on reducing the risk of PTB.

However, our study is not without limitations. The observational design limits causal inference. Residual confounding and self-reported dietary and supplementation data may have introduced bias, such as recall bias. The HLI did not account for weekend markets, pop-up restaurants/cafés, or other non-permanent outlets, potentially overlooking locations frequently visited by participants and thereby influencing the apparent importance of environmental factors. It also does not capture which neighbourhood features are used; for example, a participant may have access to a local green space but regularly use one outside their neighbourhood, which would not be reflected in their assigned HLI. In addition, the environmental exposure data (HLI) were limited to the 2013–2018 period due to historical data availability, introducing potential temporal misclassification, although these data represent the best available source on neighbourhood environments for Aotearoa New Zealand at present. Further, while the use of urban/rural classification as a clustering variable partially accounts for geographic variation, other unmeasured contextual factors may influence outcomes. These factors may have contributed to the absence of significant findings in certain areas. Another limitation of this study is that one model (Model 3) included in the analysis was exploratory, as it exceeded the recommended EPP ratio due to the relatively low prevalence of PTB. This raises the risk of overfitting and unstable estimates; therefore, findings from this model should be interpreted with caution and primarily regarded as hypothesis-generating. Finally, although our multivariable models considered multiple individual, sociodemographic, and environmental factors simultaneously, we did not explicitly examine joint exposure profiles or interaction effects (e.g., combinations of anaemia, smoking, and adverse environmental conditions).

Future research should extend this work by modelling multiple risk factors together, including interaction terms and cumulative risk scores, to identify high-risk combinations of clinical and environmental exposures that more closely reflect real-world experience than single exposures considered separately. Future studies should also incorporate more granular measurements of dietary intake, micronutrient supplementation, and environmental exposures, for example through repeated dietary records to improve assessment of adherence and exposure. Advanced longitudinal approaches, such as marginal structural or other weighted panel models, could be used to account for time-varying confounding and temporality. Longitudinal interventions targeting modifiable dietary and micronutrient practices should be rigorously evaluated in diverse populations to enhance generalisability. Our findings on non-adherence to the breads and cereals MoH guideline warrant further mechanistic and qualitative work on dietary pattern classification and socio-economic food accessibility to better understand underlying pathways. Further research is also needed to assess whether targeted health-care interventions, such as improved rural maternity transport services or telemedicine-based antenatal care, could mitigate spatial variations and reduce PTB risk in this population. The observed geographic disparities highlight the need for more spatial analyses of health-care access and birth outcomes in New Zealand.

5. Conclusion

This retrospective cohort study is the first to examine spatial variation in preterm birth risk within a diverse cohort of pregnant women in Aotearoa New Zealand, allowing a nuanced assessment of differences between regions. The findings highlight the complexity of factors influencing pregnancy outcomes, particularly the roles of maternal diet quality, micronutrient supplementation, and geographic context in shaping PTB risk. Future research should evaluate targeted interventions to improve maternal diet, optimise micronutrient supplementation, enhance screening and management of iron deficiency, and assess their impact on pregnancy outcomes. Additionally, further studies should explore interactions between multiple risk factors. Such work could inform more tailored, place-based public health strategies and may offer a pathway to improved perinatal outcomes and reduced inequities.

Data sharing statement

All GUiNZ data collected for this study are currently available by application to the Growing Up in New Zealand Data Access Committee (dataaccess@growingup.co.nz). Other data can be requested through the Liggins Institute Data Access Committee.

Funding

None to declare.

CRediT authorship contribution statement

Cristal Salatas: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Writing – original draft, Writing – review & editing. **Matt Hobbs:** Data curation, Methodology, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Frank H. Bloomfield:** Conceptualization, Supervision, Writing – review & editing. **Tanith Alexander:** Supervision, Writing – review & editing. **Clare R. Wall:** Conceptualization, Methodology, Resources, Supervision, Validation, Writing – review & editing.

Conflicts of interest

None to declare.

Acknowledgements

The Growing Up in New Zealand study was designed and conducted by the Growing Up in New Zealand Study Team, led by the University of Auckland. The authors thank the families and all members of the Growing Up in New Zealand team, including the research and operations teams, as well as the Kaitiaki and Scientific Advisory Groups. The authors thank and acknowledge the contributions of the original study investigators: Susan M.B. Morton, Polly E. Atatoa Carr, Cameron C. Grant, Arier C. Lee, Dinusha K. Bandara, Jatender Mohal, Jennifer M. Kinlock, Johanna M. Schmidt, Mary R. Hedges, Vivienne C. Ivory, Te Kani R. Kingi, Renee Liang, Lana M. Perese, Elizabeth Peterson, Jan E. Pryor, Elaine Reese, Elizabeth M. Robinson, Karen E. Waldie and Clare R. Wall. The views reported in this paper are those of the authors and do not necessarily represent the views of the Growing Up in New Zealand investigators. The authors would also like to thank Daniel E. Exeter for his support with the spatial standard operating procedure (SOP).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2025.103597.

Data availability

Data will be made available on request.

References

Abuosi, A.A., Anaba, E.A., Daniels, A.A., Baku, A.A.A., Akazili, J., 2024. Determinants of early antenatal care visits among women of reproductive age in Ghana: evidence from the recent maternal health survey. BMC Pregnancy Childbirth 24 (1), 309. https://doi.org/10.1186/s12884-024-06490-3.

Al-Naseem, A., Sallam, A., Choudhury, S., Thachil, J., 2021. Iron deficiency without anaemia: a diagnosis that matters. Clin. Med. 21 (2), 107–113. https://doi.org/10.7861/clinmed.2020-0582.

Beere, P., 2016. Creating a Road Network Analysis Layer with Travel Time Estimates Using open-source Data. GeoHealth Laboratory, New Zealand.

Bekkar, B., Pacheco, S., Basu, R., DeNicola, N., 2020. Association of air pollution and heat exposure with preterm birth, low birth weight, and stillbirth in the US: a systematic review. JAMA Netw. Open 3 (6), e208243. https://doi.org/10.1001/jamanetworkopen.2020.8243.

Bloch, J.R., 2011. Using geographical information systems to explore disparities in preterm birth rates among foreign-born and U.S.-born black mothers. J. Obstet. Gynecol. Neonatal Nurs. : JOGNN / NAACOG 40 (5), 544–554. https://doi.org/10.1111/j.1552-6909.2011.01273.x.

Burke, R.M., Leon, J.S., Suchdev, P.S., 2014. Identification, prevention and treatment of iron deficiency during the first 1000 days. Nutrients 6 (10), 4093–4114. https://doi.org/10.3390/nu6104093.

Calje, E., Skinner, J., 2017. The challenge of defining and treating anemia and iron deficiency in pregnancy: a study of New Zealand midwives' management of iron status in pregnancy and the postpartum period. Birth 44 (2), 181–190. https://doi.org/10.1111/birt.12282.

Campbell, M., Marek, L., Hobbs, M., 2021. Reconsidering movement and exposure: towards a more dynamic health geography. Geography Compass 15 (6), e12566. https://doi.org/10.1111/gec3.12566.

Chia, A.-R., Chen, L.-W., Lai, J.S., Wong, C.H., Neelakantan, N., van Dam, R.M., Chong, M.F.-F., 2019. Maternal dietary patterns and birth outcomes: a systematic review and meta-analysis. Adv. Nutr. 10 (4), 685–695. https://doi.org/10.1093/advances/nmy123.

Delker, E., Bandoli, G., LaCoursiere, Y., Ferran, K., Gallo, L., Oren, E., Gahagan, S., Ramos, G.A., Allison, M., 2022. Chronic hypertension and risk of preterm delivery: national longitudinal study of adolescents to adult health. Paediatr. Perinat. Epidemiol. 36 (3), 370–379. https://doi.org/10.1111/ppe.12858.

Dixon, L., Neely, E., Eddy, A., Raven, B., Bartle, C., 2020. Maternal socio-economic disadvantage in Aotearoa New Zealand and the impact on midwifery care. New Zealand College Midwives J. 56, 26–34. https://doi.org/10.12784/nzcomjnl56.2020.4.26-34.

Dolatian, M., Sharifi, N., Mahmoodi, Z., 2018. Relationship of socioeconomic status, psychosocial factors, and food insecurity with preterm labor: a longitudinal study. Int. J. Reproduct. Biomed. 16 (9), 563–570.

Esposito, G., Mauri, P.A., Cipriani, S., Franchi, M., Corrao, G., Parazzini, F., 2022. The role of maternal age on the risk of preterm birth among singletons and multiples: a retrospective cohort study in Lombardy, Northern Italy. BMC Pregnancy Childbirth 22 (1), 234. https://doi.org/10.1186/s12884-022-04552-y.

ESRI, 2019. ArcGIS desktop: ArcGIS pro. https://www.esri.com/en-us/arcgis/products/arcgis-pro/overview.

Etzel, R.A., 2020. Is the environment associated with preterm birth? JAMA Netw. Open 3 (4), e202239. https://doi.org/10.1001/jamanetworkopen.2020.2239.

Finkelstein, J.L., Cuthbert, A., Weeks, J., Venkatramanan, S., Larvie, D.Y., De-Regil, L.M., Garcia-Casal, M.N., 2024. Daily oral iron supplementation during pregnancy. Cochrane Database Syst. Rev. 8. https://doi.org/10.1002/14651858.CD004736.pub6.

Finkelstein, J.L., Kurpad, A.V., Bose, B., Thomas, T., Srinivasan, K., Duggan, C., 2020. Anaemia and iron deficiency in pregnancy and adverse perinatal outcomes in Southern India. Eur. J. Clin. Nutr. 74 (1), 112–125. https://doi.org/10.1038/s41430-019-0464-3.

Gambling, L., Lang, C., McArdle, H.J., 2011. Fetal regulation of iron transport during pregnancy. Am. J. Clin. Nutr. 94, S1903–S1907. https://doi.org/10.3945/ajcn.110.000885.

Gete, D.G., Waller, M., Mishra, G.D., 2019. Effects of maternal diets on preterm birth and low birth weight: a systematic review. Br. J. Nutr. 123 (4), 446–461. https://doi.org/10.1017/S0007114519002897.

Hobbs, M., Green, M.A., Griffiths, C., Jordan, H., Saunders, J., Grimmer, H., McKenna, J., 2017. Access and quality of parks and associations with obesity: a cross-sectional study. SSM - Popul. Health 3, 722–729. https://doi.org/10.1016/j.ssmph.2017.07.007.

Hobbs, M., Milfont, T.L., Marek, L., Yogeeswaran, K., Sibley, C.G., 2022. The environment an adult resides within is associated with their health behaviours, and their mental and physical health outcomes: a nationwide geospatial study. Soc. Sci. Med. 301, 114801. https://doi.org/10.1016/j.socscimed.2022.114801.

Jankowska, M.M., Yang, J.-A., Block, J., Baer, R.J., Jelliffe-Pawlowski, L.L., Flores, S., Pacheco-Warner, T., Costantino, A., Fuchs, J., Chambers, C.D., Newel, G., 2019. An online geographic data visualization tool to relate preterm births to environmental factors. Prev. Chronic Dis. 16, E102. https://doi.org/10.5888/pcd16.180498.

Khandre, V., Potdar, J., Keerti, A., 2022. Preterm birth: an overview. Cureus 14 (12), e33006. https://doi.org/10.7759/cureus.33006.

Kibret, K.T., Chojenta, C.C., Gresham, E., Tegegne, T.K., Loxton, D., 2019. Maternal dietary patterns and risk of adverse pregnancy (hypertensive disorders of pregnancy and gestational diabetes mellitus) and birth (preterm birth and low birth weight) outcomes: a systematic review and meta-analysis. Public Health Nutr. 22 (3), 506–520. https://doi.org/10.1017/S1368980018002616.

Lassi, Z.S., Salam, R.A., Haider, B.A., Bhutta, Z.A., 2013. Folic acid supplementation during pregnancy for maternal health and pregnancy outcomes. Cochrane Database Syst. Rev. 3. https://doi.org/10.1002/14651858.cd006896.pub2.

Lawrence, R.L., Wall, C.R., Bloomfield, F.H., 2022. Adherence to dietary guidelines among women with and without gestational diabetes: evidence from the growing up in New Zealand study. Nutrients 14 (10). https://doi.org/10.3390/nu14102145. Article 10.

Leader, J., Bajwa, A., Lanes, A., Hua, X., White, R.R., Rybak, N., Walker, M., 2018. The effect of very advanced maternal age on maternal and neonatal outcomes: a systematic review. J. Obstet. Gynaecol. Can. 40 (9), 1208–1218. https://doi.org/10.1016/j.jogc.2017.10.027.

Li, G., Xing, Y., Wang, G., Wu, Q., Ni, W., Jiao, N., Chen, W., Liu, Q., Gao, L., Chao, C., Li, M., Wang, H., Xing, Q., 2023. Does recurrent gestational diabetes mellitus increase the risk of preterm birth? A population-based cohort study. Diabetes Res. Clin. Pract. 199, 110628. https://doi.org/10.1016/j.diabres.2023.110628.

Lilliecreutz, C., Larén, J., Sydsjö, G., Josefsson, A., 2016. Effect of maternal stress during pregnancy on the risk for preterm birth. BMC Pregnancy Childbirth 16 (1), 5. https://doi.org/10.1186/s12884-015-0775-x.

Liu, B., Widener, M.J., Smith, L.G., Farber, S., Minaker, L.M., Patterson, Z., Larsen, K., Gilliland, J., 2022. Disentangling time use, food environment, and food behaviors using multi-channel sequence analysis. Geogr. Anal. 54 (4), 881–917. https://doi.org/10.1111/gean.12305.

Liu, B., Widener, M.J., Smith, L.G., Gesink, D., 2023. Integrating coordination of food purchasing into activity space-based food environment research: toward a household perspective. Health Place 82, 103046. https://doi.org/10.1016/j.healthplace.2023.103046.

Marek, L., Hobbs, M., Wiki, J., Kingham, S., Campbell, M., 2021. The good, the bad, and the environment: developing an area-based measure of access to health-promoting and health-constraining environments in New Zealand. Int. J. Health Geogr. 20, 16. https://doi.org/10.1186/s12942-021-00269-x.

Marek, L., Wiki, J., Campbell, M., Kingham, S., Sabel, C., Tomintz, M., Hobbs, M., 2020. Slipping under the radar: worsened health outcomes in semi-urban areas of New Zealand. N. Z. Med. J. 133 (1519), 121–125.

McHale, P., Maudsley, G., Pennington, A., Schlüter, D.K., Barr, B., Paranjothy, S., Taylor-Robinson, D., 2022. Mediators of socioeconomic inequalities in preterm birth: a systematic review. BMC Public Health 22 (1), 1134. https://doi.org/10.1186/s12889-022-13438-9.

Ministry of Health, 2008. Food and Nutrition Guidelines for Healthy Pregnant and Breastfeeding Women: a Background Paper. Ministry of Health, Wellington, N.Z, 2008. https://natlib.govt.nz/records/21454889.

Ministry of Health, 2020. Eating and activity guidelines for New Zealand adults—2020. https://www.tewhatuora.govt.nz/assets/For-the-health-sector/Health-sector-guidance/Active-Families/eating-activity-guidelines-new-zealand-adults-updated-2020-oct22.pdf.

Morton, S., Atatoa Carr, P.E., Grant, C.C., Robinson, E.M., Bandara, D.K., Bird, A., Ivory, V.C., Kingi, T.K.R., Liang, R., Marks, E.J., Perese, L.M., Peterson, E.R., Pryor, J.E., Reese, E., Schmidt, J.M., Waldie, K.E., Wall, C., 2013. Cohort profile: growing up in New Zealand. Int. J. Epidemiol. 42 (1), 65–75. https://doi.org/10.1093/ije/dyr206.

Morton, S., Grant, C.C., Wall, C.R., Carr, P.E.A., Bandara, D.K., Schmidt, J.M., Ivory, V., Inskip, H.M., Jr, C.A.C., 2014. Adherence to nutritional guidelines in pregnancy: evidence from the growing up in New Zealand birth cohort study. Public Health Nutr. 17 (9), 1919–1929. https://doi.org/10.1017/S1368980014000482.

Morton, S., Ramke, J., Kinloch, J., Grant, C.C., Carr, P.A., Leeson, H., Lee, A.C.L., Robinson, E., 2015. Growing up in New Zealand cohort alignment with all New Zealand births. Aust. N. Z. J. Publ. Health 39 (1), 82–87. https://doi.org/10.1111/1753-6405.12220.

Nesro, J., Dhinsa, M., Gelan, M., 2021. Prevalence of high risk pregnant women who attend antenatal care and associated factors in Jimma Medical Center, Jimma Town, South Western Ethiopia. Int. J. Women. Health Wellness 7 (2), 133. https://doi.org/10.23937/2474-1353/1510133.

Ogneva-Himmelberger, Y., Dahlberg, T., Kelly, K., Simas, T.A.M., 2015. Using geographic information science to explore associations between air pollution, environmental amenities, and preterm births. AIMS Public Health 2 (3), 469–486. https://doi.org/10.3934/publichealth.2015.3.469.

Ogundimu, E.O., Altman, D.G., Collins, G.S., 2016. Adequate sample size for developing prediction models is not simply related to events per variable. J. Clin. Epidemiol. 76, 175–182. https://doi.org/10.1016/j.jclinepi.2016.02.031.

Peña-Rosas, J.P., De-Regil, L.M., Garcia-Casal, M.N., Dowswell, T., 2015. Daily oral iron supplementation during pregnancy. Cochrane Database Syst. Rev. 2015 (7), CD004736. https://doi.org/10.1002/14651858.CD004736.pub5.

Picciano, M.F., 2003. Pregnancy and lactation: physiological adjustments, nutritional requirements and the role of dietary supplements. J. Nutr. 133 (6), 1997S–2002S. https://doi.org/10.1093/jn/133.6.1997S.

R Core Team, 2023. R: the R project for statistical computing. https://www.r-project.org/.

Raghavan, R., Dreibelbis, C., Kingshipp, B.L., Wong, Y.P., Abrams, B., Gernand, A.D., Rasmussen, K.M., Siega-Riz, A.M., Stang, J., Casavale, K.O., Spahn, J.M., Stoody, E.E., 2019. Dietary patterns before and during pregnancy and maternal outcomes: a systematic review. Am. J. Clin. Nutr. 109, 705S–728S. https://doi.org/10.1093/ajcn/nqy216.

Richterman, A., Raymonville, M., Hossain, A., Millien, C., Joseph, J.P., Jerome, G., Franke, M.F., Ivers, L.C., 2020. Food insecurity as a risk factor for preterm birth: a prospective facility-based cohort study in rural Haiti. BMJ Glob. Health 5 (7), e002341. https://doi.org/10.1136/bmjgh-2020-002341.

Riley, R.D., Snell, K.I., Ensor, J., Burke, D.L., Harrell, F.E., Moons, K.G., Collins, G.S., 2019. Minimum sample size for developing a multivariable prediction model: PART II - binary and time-to-event outcomes. Stat. Med. 38 (7), 1276–1296. https://doi.org/10.1002/sim.7992.

Root, E.D., Bailey, E.D., Gorham, T., Browning, C., Song, C., Salsberry, P., 2020. Geovisualization and spatial analysis of infant mortality and preterm birth in Ohio, 2008-2015: opportunities to enhance spatial thinking. Publ. Health Rep. 135 (4), 472–482. https://doi.org/10.1177/0033354920927854.

Salatas, C., Bronnert, A., Lawrence, R., Alexander, T., Wall, C., Bloomfield, F.H., Lin, L., 2025. Dietary patterns and diet quality before and/or during pregnancy and how these affect birth outcomes: a systematic review & meta-analysis. Adv. Nutr., 100490 https://doi.org/10.1016/j.advnut.2025.100490.

Salmond, C., Crampton, P., Atkinson, J., 2007. NZDep2006 Index of Deprivation. Department of Public Health University of Otago, Wellington.

Solomon, B.C., Nikolaev, B.N., Shepherd, D.A., 2022. Does educational attainment promote job satisfaction? The bittersweet trade-offs between job resources, demands, and stress. J. Appl. Psychol. 107 (7), 1227–1241. https://doi.org/10.1037/apl0000904.

South, A.P., Jones, D.E., Hall, E.S., Huo, S., Meinzen-Derr, J., Liu, L., Greenberg, J.M., 2012. Spatial analysis of preterm birth demonstrates opportunities for targeted intervention. Matern. Child Health J. 16 (2), 470–478. https://doi.org/10.1007/s10995-011-0748-2.

Statista, 2023. Percentage of preterm births in the United States from 1990 to 2023. https://www.statista.com/statistics/276075/us-preterm-birth-percentage/.

StatsNZ, 2004. of the review of the measurement of ethnicity: june 2004. https://statsnz.contentdm.oclc.org/digital/collection/p20045coll1/id/1460/.

StatsNZ, 2006. New Zealand: an urban/rural Profile. Government of New Zealand, Wellington (NZ).

StatsNZ, 2019. Statistical standard for geographic areas 2018: new standard released. https://www.stats.govt.nz/methods/statistical-standard-for-geographic-areas-2018/.

Stoody, E.E., Spahn, J.M., Casavale, K.O., 2019. The pregnancy and birth to 24 months project: a series of systematic reviews on diet and health. Am. J. Clin. Nutr. 109, 685S–697S. https://doi.org/10.1093/ajcn/nqy372.

Te Whatu Ora, 2022. Report on maternity web tool – te Whatu Ora—Health New Zealand. https://www.tewhatuora.govt.nz/our-health-system/data-and-statistics/report-on-maternity-web-tool/.

Te Whatu Ora, 2023. Iron in pregnancy | Te Whatu Ora. https://www.nationalwomenshealth.adhb.govt.nz/healthprofessionals/referrals-and-information/maternity/iron-in-pregnancy/.

Tipton, M.J., Wagner, S.A., Dixon, A., Westbay, L., Darji, H., Graziano, S., 2020. Association of living in a food desert with pregnancy morbidity. Obstet. Gynecol. 136 (1), 140. https://doi.org/10.1097/AOG.0000000000003868.

von Elm, E., Altman, D.G., Egger, M., Pocock, S.J., Gøtzsche, P.C., Vandenbroucke, J.P., 2007. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. Prev. Med. 45 (4), 247–251. https://doi.org/10.1016/j.ypmed.2007.08.012.

Wall, C.R., Gammon, C.S., Bandara, D.K., Grant, C.C., Atatoa Carr, P.E., Morton, S.M.B., 2016. Dietary patterns in pregnancy in New Zealand—Influence of maternal socio-demographic, health and lifestyle factors. Nutrients 8 (5), 300. https://doi.org/10.3390/nu8050300.

Watson, P.E., McDonald, B.W., 2010. The association of maternal diet and dietary supplement intake in pregnant New Zealand women with infant birthweight. Eur. J. Clin. Nutr. 64 (2), 184–193. https://doi.org/10.1038/ejcn.2009.134.

WHO, 2023. Preterm birth. https://www.who.int/news-room/fact-sheets/detail/preterm-birth.

Wilkins, E., Radley, D., Morris, M., Hobbs, M., Christensen, A., Marwa, W.L., Morrin, A., Griffiths, C., 2019. A systematic review employing the GeoFERN framework to examine methods, reporting quality and associations between the retail food environment and obesity. Health Place 57, 186–199. https://doi.org/10.1016/j.healthplace.2019.02.007.

Willingham, L., Gordon, J., Stokes, E., Scott, W., Fleenor, R., 2020. 402: association between food deserts and pregnancy outcomes. Am. J. Obstet. Gynecol. 222 (1), S265–S266. https://doi.org/10.1016/j.ajog.2019.11.418.

Zar, H.J., Pellowski, J.A., Cohen, S., Barnett, W., Vanker, A., Koen, N., Stein, D.J., 2019. Maternal health and birth outcomes in a South African birth cohort study. PLoS One 14 (11), e0222399. https://doi.org/10.1371/journal.pone.0222399.