



Original Article

Changes in residential greenness between pregnancies and birth outcomes: longitudinal evidence from Michigan births 1990–2012

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Abstract

Background: Residential exposure to greenness is associated with better birth outcomes, but it remains unknown whether this is explained by maternal characteristics associated with both place of residence and birth outcomes. We examined whether changes in residential greenness are associated with preterm birth (PTB) and birthweight.

Methods: We examined cross-sectional associations between maternal exposure to residential greenness [normalized difference vegetation index (NDVI)] and PTB (<37 weeks of gestation) and birthweight in grams, using all births in Michigan (1990–2012) linked by mother ($n = 1\,730\,424$). We used maternal fixed effects analysis to estimate associations within mothers across multiple pregnancies and associations for mothers who did not move, but for whom greenness changed between pregnancies, to mimic an intervention.

Results: Each 0.1-unit change in NDVI was associated with 0.98 [95% confidence interval (CI): 0.97, 0.99] times lower odds of PTB and a 9.0 (95% CI: 8.1, 9.9)-gram increase in birthweight after adjusting for individual and neighbourhood covariates. When we controlled for time-invariant maternal unmeasured confounders; these associations were close to null [odds ratio (OR): 1.00 (95% CI: 0.98, 1.01); β : -0.3 (95% CI: -2.0, 3.6)]. We did not find a relationship between greenness and birth outcomes among women who did not move between pregnancies, but for whom greenness changed within their residential location (as in an intervention).

Conclusions: Residential greenness does not predict birth outcomes, after controlling for time-invariant maternal characteristics, using longitudinal evidence. Future research should explore residential selection factors, spatial and individual heterogeneity and experimental study designs.

Key words: Preterm birth, birthweight, fixed effects, greenness, green space, NDVI

Key Messages

- When comparing birth outcomes for the same mother under different conditions of residential greenness, which controls for time-invariant maternal unmeasured confounders, we found no association between greenness and birth outcomes.
- We also did not find a relationship between greenness and birth outcomes among women whose location of residence did not change between pregnancies, but for whom greenness changed within their residential location (as in an intervention on greenness).
- It appears that other maternal and/or neighbourhood characteristics may be more important predictors of preterm birth or low birthweight, compared with neighbourhood greenery.

Introduction

Increasingly, ‘green spaces’ (e.g. parks, tree canopy and other vegetation) are explored for their salutogenic benefits for nearby residents, including mental health,^{1,2} health-related behaviours including physical activity,³ and maternal and child health outcomes. In fact, higher levels of residential greenness are associated with higher birthweight and reduced risk of low birthweight,⁴ and in two North American settings, higher greenness has been linked to reduced risk of preterm birth.^{5,6} However, findings are not entirely consistent.^{4,7,8}

A link between residential greenness and improved birth outcomes is particularly promising, because the USA exhibits higher rates of adverse birth outcomes, such as low birthweight and preterm birth (PTB), than any other high-income nation.^{9,10} Thus far, clinical, public health and behavioural interventions have not succeeded in reducing the USA’s high rates of adverse birth outcomes or eliminating stark racial/ethnic disparities in these outcomes. On the contrary, rates of PTB have risen in recent years, and non-Hispanic Black women remain at 50% higher risk of delivering preterm compared with non-Hispanic White women.¹¹ Although neighbourhood-level factors (e.g. neighbourhood deprivation) are strongly associated with increased risk of adverse birth outcomes,¹² many of these factors are difficult to modify and interventions encouraging neighbourhood mobility have had mixed impacts on health.¹³

Residential greenness, on the other hand, tends to be relatively inexpensive and feasible to modify at the community level,¹⁴ even as the USA and the world become more urbanized, and could thus provide a promising target for intervention if greenness is found to improve adverse birth outcomes. However, previous research on this topic has been limited to demonstrating cross-sectional associations: mothers who live in areas with higher greenness have fewer adverse birth outcomes.⁴ Inference from these

findings is limited because measured and unmeasured maternal characteristics associated with birth outcomes may also predict where women live, a form of bias often referred to as ‘differential selection’ into residential area. It remains unknown whether a woman would have a lower risk of an adverse birth outcome if greenness within her residential area increased while she remained in place, as in an interventional study.

Thus, leveraging both fine resolution, annual satellite imagery and a large database ($n = 1\,730\,424$) of all births in Michigan over a 22-year period (1990–2012) that uniquely links births to the same mothers over time, our study aimed to: (i) replicate previous studies testing for cross-sectional associations between residential greenness during pregnancy and birth outcomes (PTB, birthweight), adjusted for a suite of maternal and neighbourhood characteristics; (ii) use a within-mother analysis to control for unmeasured maternal confounding; and (iii) test whether associations persist among mothers who did not move between births but experienced changes in residential greenness from one birth to the next.

Methods

Ethical approval

Health data for this study were approved by Michigan State University’s Institutional Review Board and the Michigan Department of Health and Human Services (MDHHS) (#201505-08-XA).

Maternal and infant data

We used Michigan birth certificate data, linked by mother, from 1990 to 2012 ($n = 2\,991\,295$ births). Residential addresses of each mother at the time of delivery were geocoded to produce a latitude and longitude, by MDHHS.

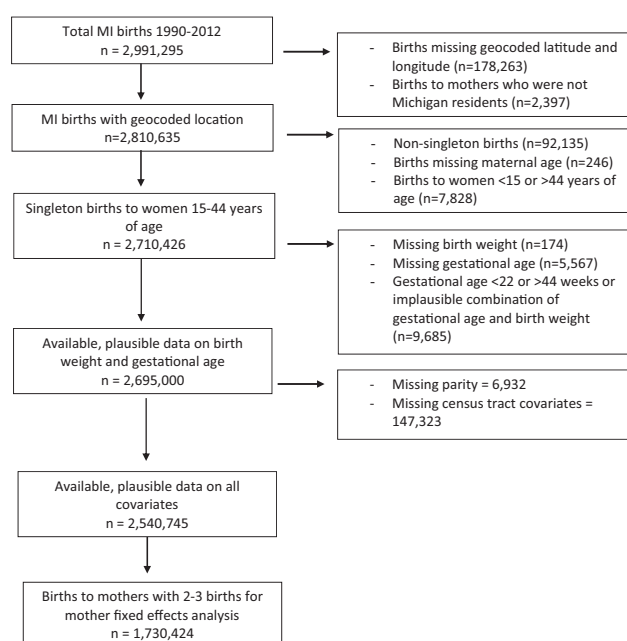


Figure 1 Analytical sample flow chart for Michigan (MI) births 1990-2010

We included singleton births to women 15-44 years of age with geocoded residential addresses and plausible, non-missing data on birthweight, gestational age and covariates ($n=2\,540\,745$, see [Figure 1](#)). For our within-mother analysis, we focused on a sample of mothers with either two or three singleton births in the dataset ($n=1\,730\,424$ births to 737 878 mothers).

Outcomes

Our primary outcomes were preterm birth (PTB) defined as birth at <37 weeks of gestation and birthweight in grams.

Individual-level covariates

Maternal characteristics included: age, race/ethnicity, parity and educational attainment (see [Table 1](#) for categories).

Exposure

Our primary exposure was residential greenness for the mother's geocoded address in the calendar year during which the majority (>4 months) of her pregnancy occurred (i.e. either the same year as the birth or the preceding year) calculated using the Landsat 5 and 7 satellite data for normalized difference vegetation index (NDVI). We used the annual data for the greenest-pixel TOA (Top-Of-

Atmosphere) reflectance composites with a spatial resolution (cell size) of 30 m. We generated a 200-m circular buffer around each mother's residential address (i.e. radius size = 100 m) and extracted the peak greenness for all cells within the buffer. We then averaged these cell values to generate an indicator of peak greenness for the residential location of the mother at the time of each birth [values range from 0 (low) to 1 (high) greenness]. We also explored a larger buffer size, 500 m, commonly used in neighbourhood-based research. However, results were almost identical to those using a 200-m buffer (see [Supplementary Tables S1 and S2](#), available as [Supplementary data](#) at *IJE* online).

Movers vs stayers

We defined movers as mothers with two or three births during the study period, whose geocoded latitude changed by a magnitude of ≥ 0.01 between either births 1 and 2 or births 2 and 3. Stayers were mothers who had two or three births but did not move between those births. Change in greenness was defined as a change in NDVI of ≥ 0.1 between births, among stayers only.

Neighbourhood-level covariates

Using census tract data from each decade (1990, 2000, 2010), we extracted the following neighbourhood characteristics as percentages among adults: non-Hispanic White, with a bachelor's degree, unemployed, and living below the poverty line. We also compiled data on median household income and population density (population/km²). Each birth was assigned neighbourhood characteristics based on the census tract in which the mother's address fell and the year of the birth. We used the following scheme to assign birth years to census data: births 1990-94 (1990 census), 1995-2004 (2000 census) and 2005-12 (2010 census).

Statistical analyses

We described our analytical sample using means [standard deviation (SD)] for continuous variables and frequency (percent) for categorical variables. Our multivariable modelling proceeded as follows.

Step 1

We conducted a series of regression models (logistic regression for PTB and linear regression for birthweight), adding additional covariates to each model. Model 1 included only mean greenness. Model 2 added exposure year and birth month indicator variables to control for secular

Table 1 Characteristics of three analytical samples of Michigan singleton births 1990-2012

	Full analytical sample <i>n</i> = 2 540 745	Within-mother sample ^a <i>n</i> = 1 730 424 <i>n</i> (%)	Stayers ^b <i>n</i> = 1 225 620
Individual variables			
Maternal age			
<20	275 407 (10.8)	174 905 (10.1)	91 632 (7.5)
20-29	1 373 602 (54.1)	970 258 (56.1)	656 447 (53.6)
30-39	845 578 (33.3)	561 521 (32.5)	457 594 (37.3)
≥40	46 158 (1.8)	23 740 (1.4)	19 947 (1.6)
Maternal race/ethnicity			
NH White	1 820 308 (71.6)	1 262 066 (72.9)	918 226 (74.9)
NH Black	486 428 (19.2)	322 445 (18.6)	205 882 (16.8)
Hispanic	134 225 (5.3)	87 967 (5.1)	60 015 (4.9)
NH Asian/Pacific Islander	65 234 (2.6)	36 405 (2.1)	27 588 (2.3)
NH American Indian/Alaska Native	11 408 (0.5)	7592 (0.4)	5027 (0.4)
Unknown/multiple	23 142 (0.9)	13 949 (0.8)	8 882 (0.7)
Maternal education			
<High school	441 025 (17.4)	301 367 (17.4)	183 779 (15.0)
High school diploma or some college	1 471 517 (57.9)	988 029 (57.1)	689 723 (56.3)
College degree or more	597 245 (23.5)	419 346 (24.2)	335 957 (27.4)
Missing	30 958 (1.2)	21 682 (1.3)	16 161 (1.3)
Maternal parity/previous live births			
None	1 022 401 (40.2)	577 947 (33.4)	373 392 (30.5)
1	822 603 (32.4)	643 495 (37.2)	465 779 (38.0)
2 or more	695 741 (27.4)	508 982 (29.4)	386 449 (31.5)
Preterm birth	198 679 (7.8)	131 582 (7.6)	91 370 (7.5)
Neighbourhood variables		Mean (SD)	
Mean greenness within 200 m of residence ^c	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)
Median household income, in US\$1000 ^d	43.0 (19.8)	43.7 (19.0)	45.3 (20.3)
Percent NH White ^d	74.0 (31.7)	74.3 (31.5)	75.5 (30.6)
Percent with bachelor's degree ^d	11.8 (8.2)	11.8 (8.2)	12.2 (8.3)
Percent unemployed ^d	7.5 (6.4)	7.3 (6.3)	7.1 (6.2)
Population density/km ^d	1262.9 (1252.9)	1253.0 (1247.3)	1219.3 (1226.6)
Total population ^d	4318.6 (1675.9)	4334.7 (1684.7)	4355.5 (1690.8)

^aBirths to mothers with 2-3 births in the dataset.^bBirths to mothers with 2-3 births, who did not move between those births.^cNDVI ranges from low (0) to high (1).^dWithin mother's census tract of residence.

trends and seasonality, respectively, that could affect both birth outcomes and greenness. Model 3 added individual-level covariates. Model 4 added neighbourhood-level covariates. Results of this first set of analyses tell us the association between mean greenness and birth outcomes (PTB, birthweight) overall and adjusted for potential confounders. All models included standard errors clustered by mother. We considered clustering standard errors by census tract as well; however, because mothers move throughout the study period, clustering would occur within year-tract combinations (not within tract alone). To determine the extent of clustering by census tract, we thus ran separate multilevel regression models (using Model 4) for each year (1990 through 2012) for the birthweight outcome, with clustering by tract. The intraclass correlation

coefficient (ρ) for all models was <0.01 (highest ρ was 0.009), indicating that clustering by census tract is unlikely to influence our analyses.

Step 2

We used the set of births to mothers with two or three births in the dataset (i.e. the 'within-mother sample') to conduct a within-mother analysis. To do this, we used maternal fixed effects (FE) analyses (i.e. conditional logistic/linear regressions) that use a mother-specific indicator variable to provide complete control for observed and unobserved time-invariant characteristics of the mothers which might influence both where they live (i.e. 'selection' into residential area) and their birth outcomes. The results of this second set of analyses tell us the association between

greenness and birth outcomes, comparing births within the same mothers but with a different exposure to greenness (due either to the mother moving or to changes in the level of greenness in her residential area between births).

Step 3

Among mothers who did not move residences between births 1 and 2 or 2 and 3 (i.e. 'stayers'), we used the same FE approach to examine the association between changes in greenness and birth outcomes. The results of this third-set of analyses tell us the association between changes in the level of greenness in a mother's area of residence and birth outcomes, among mothers who do not move. These results are most closely related to an intervention that aims to change greenness.

We also conducted several robustness tests. We compared the findings from the fully-adjusted (Model 4) linear and logistic regression analyses from Step 1 using three different samples. First, we excluded women missing education ($n=34\ 282$). In our original models, we used a missing indicator variable, which can induce bias.¹⁵ Second, we compared findings from the overall sample with those from the fixed-effect sample from Step 2 and the stayer sample from Step 3, to ensure that any differences in results between Step 1 findings and those from Steps 2 and 3 were due to the maternal FE approach and not the composition of the sample.

Results

The majority (71.6%) of births in our sample were to mothers of non-Hispanic (NH) White race/ethnicity, with 19.2% to mothers of NH Black race/ethnicity (Table 1). Almost 60% of births were to mothers with a high school diploma or some college, and 23.5% were to mothers with a bachelor's degree or more (Table 1). Of all births, 7.8% were preterm, and mean (SD) birthweight was 3350.6 g (581.1 g). Table 1 also shows characteristics of births in the 'fixed effects' ($n=1\ 730\ 424$) and 'stayer' ($n=1\ 225\ 620$) samples. 'Stayers' were slightly older, more frequently NH White, college-educated and had higher parity. Importantly, mean residential greenness (0.5 in all samples), percent PTB (7.6 in the within-mother sample and 7.5% in the stayer sample) and mean birthweight (3364.9 g in the two-to-three births sample and 3381.4 g in the stayer sample) did not differ substantially by sample.

Step 1 results

In unadjusted analyses, each 0.1-change in greenness (NDVI) was associated 0.90 times lower odds of PTB (95% CI: 0.89, 0.90) (Table 2). After adjusting for all potential confounders, this odds ratio (OR) was 0.98 (95%

CI: 0.97, 0.99), indicating that most—although not all—of the association between greenness and PTB was accounted for by differences in measured individual- and neighbourhood-level covariates associated with both variables (Table 2). Similarly, a 0.1-increase in greenness was associated with a 47.0 g (95% CI: 46.2, 47.8) increase in birthweight before inclusion of covariates, which was attenuated to 9.0 g (95% CI: 8.1, 9.9) after adjustment for all potential confounders (Table 3).

Steps 2 and 3 results

When comparing birth outcomes within mothers with different levels of exposure to greenness across different pregnancies, i.e. both movers and stayers for whom greenness changed, we found that each 0.1-increase in greenness was no longer associated with PTB (OR 1.00, 95% CI: 0.98, 1.01) or birthweight ($\beta = -0.3$, 95% CI: -1.6 , 1.0) (Table 4). When we limited our analysis to 'stayers', we found that changes in greenness in a mother's residential area, when she did not move, were also not associated with PTB (OR: 1.00, 95% CI: 0.97, 1.03) or birthweight ($\beta = 0.8$, 95% CI: -2.0 , 3.6) (Table 4).

Results from the Step 1 logistic and linear regressions (Model 4), using alternative samples, were substantively similar to the original findings (Supplementary Tables S1 and S2). Due to the null findings in Table 4 (Steps 2 and 3), we *post-hoc* hypothesized that a 0.1-unit change in NDVI might reflect changes in rainfall or other minor changes in greenness and might not represent a meaningful change in greenness. Thus, we also ran a second set of analyses for Steps 2 and 3, where we restricted to women with only two births in the dataset and who experienced changes in greenness between those births of 0.3 NDVI. Results from these analyses also did not demonstrate associations between changes in greenness of 0.3 NDVI between births and either PTB or birthweight (Supplementary Table S3, available as Supplementary data at IJE online).

Discussion

Among births in Michigan between 1990 and 2012, we found that maternal exposure to residential greenness was associated with lower odds of PTB and higher birthweight, even after adjusting for individual- and neighbourhood-level covariates. However, when we used a within-mother analysis to control for time-invariant maternal unmeasured confounders that might be associated with both place of residence and birth outcomes, these associations were close to the null. We also did not find a relationship between greenness and birth outcomes among women whose location of residence did not change between pregnancies, but

Table 2 Multivariable-adjusted odds ratios for preterm birth (<37 weeks of gestation) among Michigan singleton births 1990–2012 (*n* = 2 540 745)

	Model 1	Model 2	Model 3	Model 4
	OR (95% CI)			
Mean greenness within 200 m ^a	0.90 (0.89, 0.90)	0.89 (0.88, 0.89)	0.96 (0.96, 0.97)	0.98 (0.97, 0.99)
Maternal age				
<20			0.94 (0.92, 0.96)	0.94 (0.92, 0.95)
20–29			Ref	Ref
30–39			1.23 (1.21, 1.24)	1.24 (1.22, 1.25)
≥40			1.63 (1.58, 1.68)	1.65 (1.60, 1.70)
Maternal race/ethnicity				
NH White			Ref	Ref
NH Black			1.88 (1.85, 1.90)	1.62 (1.59, 1.65)
Hispanic			0.95 (0.93, 0.97)	0.90 (0.88, 0.93)
NH Asian/Pacific Islander			0.99 (0.96, 1.02)	0.98 (0.95, 1.01)
NH American Indian/Alaska Native			1.06 (0.99, 1.14)	1.06 (0.98, 1.14)
Unknown/multiple			1.07 (1.02, 1.13)	1.05 (1.00, 1.11)
Maternal education				
<High school			1.55 (1.52, 1.58)	1.47 (1.44, 1.50)
High school diploma or some college			1.24 (1.22, 1.25)	1.20 (1.19, 1.22)
College degree or more			Ref	Ref
Missing			1.52 (1.46, 1.58)	1.48 (1.43, 1.54)
Maternal parity/previous live births				
None			Ref	Ref
1			0.77 (0.77, 0.78)	0.77 (0.76, 0.78)
2 or more			0.86 (0.84, 0.87)	0.85 (0.83, 0.86)
Adjusted for exposure year	No	Yes	Yes	Yes
Adjusted for birth month (seasonality)	No	Yes	Yes	Yes
Adjusted for neighbourhood-level covariates	No	No	No	Yes

Ref, reference group.

^a β represents a 0.1-unit change in NDVI (NDVI ranges from low = 0 to high = 1).

for whom greenness changed within their residential location (as in an intervention on greenness).

Consistent with previous literature reviewed by Banay and colleagues,⁴ we found that residential greenness was associated with increased birthweight (9.0 g), even after adjusting for individual- and neighbourhood-level covariates. In concordance with previous studies in Pennsylvania and Vancouver,^{5,6} we found that greenness was associated with reduced odds of PTB. Some previous studies demonstrated larger magnitudes of association than we did. For example, Casey and colleagues found that higher greenness in Pennsylvania was associated with a 0.78 times reduction in odds of PTB, whereas our fully-adjusted OR was 0.98.⁵ An interquartile range increase in NDVI (equivalent to a 0.1-change in NDVI in our sample) was found to be associated with increases in birthweight of up 44.2 g in Spain.⁷ The magnitude of our findings was similar to those from a study in Los Angeles finding that an interquartile range increase in NDVI was associated with an increase in birthweight of 6.1 g and a reduction in odds of PTB of 0.99.¹⁶

However, our study sheds new light on this body of work by demonstrating that the association between residential greenness and birth outcomes is close to the null once we account for maternal unmeasured confounders. This suggests that, as has been argued regarding much research on neighbourhood effects on health,¹⁷ it is difficult to tease out the impacts of neighbourhood-level factors from individual-level factors that affect people's health status as well as where they live. Previous literature demonstrating associations between greenness and birth outcomes may have been biased by unmeasured variables associated with both where women live and the outcomes of their pregnancies. Our fixed effects approach controls for these unmeasured, time-invariant maternal characteristics and finds no association.

A major strength of our study is the large sample size due to the inclusion of all births in Michigan from 1990 through 2012. Most earlier studies examining associations between residential greenness and birth outcomes have been limited to small cohort studies or states,^{18–23} although a comparable study used all births in Texas from 2000

Table 3 Multivariable-adjusted beta coefficients for birthweight in grams among Michigan singleton births 1990–2012 ($n = 2\,540\,745$)

	Model 1	Model 2	Model 3 β (95% CI)	Model 4
Mean greenness within 200 m ^a	47.0 (46.2, 47.8)	48.8 (48.0, 49.6)	12.7 (11.9, 13.5)	9.0 (8.1, 9.9)
Maternal age				
<20			0.9 (-1.9, 3.6)	2.0 (-0.8, 4.7)
20–29			Ref	Ref
30–39			-2.6 (-4.4, -0.8)	-6.3 (-8.2, -4.5)
≥40			-53.9 (-59.9, -47.8)	-58.2 (-64.2, -52.2)
Maternal race/ethnicity				
NH White			Ref	Ref
NH Black			-259.6 (-262.1, -257.1)	-214.3 (-217.8, -210.9)
Hispanic			-11.7 (-15.4, -8.0)	2.1 (-1.7, 5.8)
NH Asian/Pacific Islander			-193.2 (-197.7, -188.6)	-193.2 (-197.8, -188.5)
NH American Indian/Alaska Native			22.9 (10.8, 35.0)	25.6 (13.6, 37.7)
Unknown/multiple			-66.5 (-74.2, -58.8)	-62.0 (-69.7, -54.3)
Maternal education				
<High school			-187.8 (-190.8, -184.7)	-170.2 (-173.3, -167.0)
High school diploma or some college			-79.0 (-81.0, -77.0)	-69.2 (-71.3, -67.1)
College degree or more			Ref	Ref
Missing			-123.1 (-130.5, -115.7)	-114.4 (-121.8, -107.0)
Maternal parity/previous live births				
None			Ref	Ref
1			93.3 (91.8, 94.9)	94.5 (93.0, 96.0)
2 or more			100.8 (98.7, 102.8)	104.5 (102.5, 106.6)
Adjusted for exposure year	No	Yes	Yes	Yes
Adjusted for birth month (seasonality)	No	Yes	Yes	Yes
Adjusted for neighbourhood-level covariates	No	No	No	Yes

Ref, reference group.

^aOR for a 0.1-unit change in NDVI (NDVI ranges from low = 0 to high = 1).**Table 4** Within-mother, multivariable-adjusted associations between greenness and among Michigan singleton births 1990–2012 to mothers with 2 or 3 births in the dataset ($n = 1\,730\,424$)

	Preterm birth OR (95% CI)	Birthweight β (95% CI)
Within all mothers		
Mean greenness within 200 m ^b	1.00 (0.98, 1.01)	-0.3 (-1.6, 1.0)
Among stayers ^a only ($n = 1\,225\,620$)		
Mean greenness within 200 m ^b	1.00 (0.97, 1.03)	0.8 (-2.0, 3.6)

^aBirths to mothers with 2–3 births, who did not move between those births.^bOR and β represent a 0.1-unit change in NDVI (NDVI ranges from low = 0 to high = 1).

through 2009.²⁴ This is also the first study, of which we are aware, to compare birth outcomes between mothers for whom greenness changed between births (due either to moving or changes in residential greenness). Our maternal fixed effects approach makes a novel contribution in showing that, when comparing outcomes to the same mother across different births, there was no association between residential greenness and either PTB or birthweight.

Limitations

Limitations of this work include that NDVI is only one measure of greenness and does not account for its quality (e.g. aesthetics, species types) or accessibility or actual usage of green spaces. Since this sample is from Michigan over a 22-year period, many cities have experienced increases in vacant lots and overgrown areas due to lower tax revenue to maintain such spaces, which yield higher NDVI values but may not benefit health. Using NDVI, we

are also unable to detect whether changes are the result of variations in rainfall/drought or intentional green infrastructure (e.g. tree plantings). Moreover, spatial heterogeneity in the neighbourhood or urban/rural context within which individuals experience green space may moderate its impact on health. For example, living near a small, but safe and accessible, park may be more salubrious than living near in a large, but inaccessible or unsafe, green space.

Another potential limitation of our work is that we were unable to examine whether impacts of residential green space on birth outcomes might differ by factors that might influence individuals' ability or desire to use green space for health benefits, such as income, occupation, access to transportation or other behavioural characteristics (e.g. physical activity levels). Finally, the mechanism by which greenness could affect birth outcomes has received little attention in the literature. Kuo proposes four main pathways by which greenness could influence health in general: air quality, physical activity, stress and social integration.²⁵ To impact on birth outcomes, these mechanisms would likely have to act on maternal health both during and before pregnancy (e.g. chronic and early life stress are thought to be associated with higher risk of adverse birth outcomes²⁶) and in these data, we do not know how long mothers lived in their area of residence before giving birth. Future research should explore spatial heterogeneity in context and type of green space by incorporating urban planning or neighbourhood data. Panel data could also be used in future work to examine whether impacts of green space on birth outcomes may be heterogeneous across socioeconomic characteristics such as income, education, access to transportation or occupation.

Conclusion

Our findings are the first to show that residential greenness does not appear to predict birth outcomes, after controlling for time-invariant maternal characteristics, using longitudinal evidence. Future research could usefully explore factors that explain residential selection in order to contribute to improvements in maternal and child health outcomes. Likewise, experimental study designs to evaluate the effects of greenness interventions, including the quality and contact or usage time, on maternal and child health outcomes could illuminate the consistency in the findings observed here.

Supplementary Data

Supplementary data are available at *IJE* online

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Author Contributions

C.M. and A.P. conceived of the study. C.M. had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. A.P. led spatial analyses and generation of spatial covariates and NDVI measures, with assistance from Z.L. and J.S. C.M. led statistical analyses. C.M. and A.P. drafted the manuscript. All authors edited and approved the manuscript.

Conflict of Interest

The authors have no conflicts of interest or financial disclosures to declare.

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