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Association between Greenness, Urbanicity, and Birth Weight

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Abstract

Background—More than half of the world's population lives in urban environments. Due to urban related factors (e.g. higher air pollution), urban residents may face higher risk of adverse health outcomes, while access to green space could benefit health.

Purpose—We explored associations between urban and green land-use and birth weight.

Methods—Connecticut, U.S., birth certificate data (2000-2006) were acquired (n=239,811), and land-use data were obtained from the National Land Cover Database. We focused on three land-uses; urban space, urban open space, and green space (i.e. forest, shrub, herbaceous, and cultivated land). We estimated fractions of greenness and urbanicity within 250 m from residence. A linear mixed effects model was conducted for birth weight and a logistic mixed effects model for low birth weight (LBW) and small for gestational age (SGA).

Results—An interquartile range (IQR) increment in the fraction of green space within 250 m of residence was associated with 3.2g (95% Confidence Interval [0.4, 6.0]) higher birth weight. Similarly, an IQR increase in green space was associated with 7.6% [2.6, 12.4] decreased risk of LBW. Exposure to urban space was negatively correlated with green space (Pearson correlation = −0.88), and it showed negative association with birth outcomes. Results were generally robust with different buffer sizes and controlling for fine particles ($PM_{2.5}$) and traffic.

Conclusions—We found protective associations by green space on birth outcomes. Increasing green space and/or reducing urban space (e.g. the greening of city environments) may reduce the risk of adverse birth outcomes such as LBW and SGA. Populations living in urban environments will grow in the next half century, and allocation of green space among urban areas may play a critical role for public health in urban planning.

Keywords

Environmental Epidemiology; Birth Weight; Green spaces; Urbanicity; Built Environment[1]

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1. Introduction

Urbanization has accelerated in recent decades and is expected to accelerate further in the next few decades. Conversely, green spaces are decreasing in many areas. Currently, more than half of people live in urban environments, as defined as areas of intensive use of the land covered by structures,(Anderson et al., 1975) and about 70% of people will live in developed areas by 2050.(United Nations, 2011) While urban environments may provide several health advantages (e.g. better access to health care),(Chan et al., 2006) urban residents can face higher risk of adverse health outcomes. For instance, a U.S. study found that urban land-use was associated with the severity of wheeze symptoms in infants.(Ebisu et al., 2011) Urban environments are also associated with shorter sleeping duration for infants.(Bottino et al., 2012) These studies used the degree of urbanicity around residence to represent integrated environmental exposures that are prevalent in urban environments such as noise, traffic emission, and other factors. In general, urbanicity and greenness show negative correlations, and several researchers focused on greenness rather than urbanicity. A British study reported that moving to greener areas was associated with improved mental health.(Alcock et al., 2014) Hospitalization risk for cardiovascular disease was lower for those living in a green area in Australia.(Pereira et al., 2012) These findings could implicate that access to green space leads to lower exposures to contaminants (e.g., air pollution), increase physical activity, reduce psychological stress, and/or reflect differences in other factors compared to more urban space, resulting in health benefits.(Alcock et al., 2014; Hystad et al., 2014; Pereira et al., 2012)

Research on land-use and birth outcomes is still limited. Beneficial associations between green space and fetal growth were observed in European studies.(Dadvand et al., 2012a; Markevych et al., 2014) These associations are strongest among mothers with low socio-economic status (SES). Similarly, a protective association between green space and birth weight was found in Southern California.(Laurent et al., 2013) Although several studies have examined associations between green space and birth outcomes, none have examined this issue in the eastern U.S., a relatively populated area. Furthermore, no studies investigated association between urbanicity and birth outcomes. While greenness and urbanicity are related, they are not perfectly correlated, and both urban and green space warrant attention as they may affect birth outcomes through different pathways. In an era of urbanization, studies relating health and built environment are emerging,(Hystad et al., 2014; Miranda et al., 2012) and further studies are warranted.

Air pollution is one factor of an urban environment that may affect health, and many studies link birth outcomes to air pollution, such as nitrogen dioxide (NO_2) or particulate matter (PM).(Ebisu and Bell, 2012) Although ambient pollutants likely affects birth outcomes, (Sapkota et al., 2012) many other factors also impact birth outcomes. For instance, low SES is associated with adverse birth outcomes,(Blumenshine et al., 2010) which may relate to nutrition, baseline health status, or other factors. Lobel et al. found that pregnancy-specific stress is associated with low birth weight (LBW).(Lobel et al., 2008) Furthermore, noise levels were associated with birth weight after adjustment for air pollution.(Gehring et al., 2014) Many of these potential risk factors are related; low SES populations tend to live in urban areas, leading to higher air pollutant exposure than other populations.(Bell et al., 2011; Ebisu et al., 2014) Ideally research would include complete information on all potential risk factors, but such studies are difficult due to cost and intense data sampling. Land-use around residence has been used to represent integrated environmental exposures,(Bottino et al., 2012; Cyril et al., 2013; Ebisu et al., 2011) reflecting a suite of exposures including noise, air pollution, and other factors.

We explored associations between green/urban land-uses and birth weight in Connecticut, U.S. LBW increases risk of perinatal morbidity and mortality, and affects health later in life.(Stillerman et al., 2008) The U.S. Department of Health and Human Services aims to decrease LBW rate from 8.2% in 2007 to 7.8% in 2020.(U.S. Department of Health and Human Services. Office of Disease Prevention and Health Promotion, 2010) To achieve this goal, it is critical to unveil what factors lower birth weight. As over 80% of U.S. residents live in an urban environment,(United Nations, 2011) understanding green and urban space effects on human health is crucial.

2. Methods

2.1. Birth data

Birth certificate data for 2000/1/1 to 2006/12/31 were provided by the Connecticut Department of Public Health. Analysis was restricted to singleton births with gestational age from 37 to 44 weeks and births whose residential addresses at delivery were successfully geocoded (geocoding score ≥95). We excluded births with congenital defects or impossible gestational age and birth weight combinations.(Alexander et al., 1996) Neighborhood SES variables at census tract level, the smallest available geographic unit, were obtained from the American Community Survey 2009 for the fractions of: educational attainment less than high school among those ≥25 years, unemployment among those ≥16 years, and households with income below the poverty line as defined by family income and size, and price index. Further description of the data is available elsewhere.(Ebisu et al., 2014)

We considered birth weight as a continuous variable, LBW (birth weight <2,500 g), and small for gestational age (SGA; birth weight <10th percentile for gestational age and sex based on 1999 and 2000 U.S. births).(Oken et al., 2003) IRB approvals were obtained from the Yale University Human Investigation Committee and Connecticut Department of Public Health.

2.2. Land-use data

Land-use data were acquired through the National Land Cover Database (NLCD) 2001, which is the timeframe of available data closest to the midpoint of our study period.(Homer et al., 2007) Data were 30×30 m resolution pixels, and each pixel was assigned a unique land-use type based on Landsat satellite images.(Homer et al., 2007) The original data had 16 land-use categories. Many of these land-uses are rare in our study area (e.g. barren land), and we focused on greenness and urban-related variables. There are four types of greenness-related land-uses in NLCD: forest (i.e. deciduous, evergreen, and mixed forest), shrub, herbaceous, and cultivated land. For forest land-use, each pixel is dominated by trees higher than 5 m and at least 20% of the pixel is dominated by vegetation cover. For shrub land-use, each pixel is dominated by shrubs less than 5 m and at least 20% of the pixel is dominated by vegetation cover. Herbaceous land-use is defined as the pixel dominated by herbaceous more than 80% of total vegetation. Cultivated land is the pixel used for the production of crops, which account for more than 20% of total vegetation. These land-uses were treated as green space.

Urbanicity has been defined several ways; population size, population density, access to health service, etc.(Cyril et al., 2013) We defined urbanicity as land 'comprised of areas of intensive use with much of the land covered by structures', as was proposed by Anderson et al.(Anderson et al., 1975) We applied two urban-related categories. "Urban open space" was defined as a pixel mostly dominated by lawn grasses with a mixture of constructed materials (e.g. parking lot), and impervious surfaces accounting for $<20\%$ of each pixel. We contrast urban open space with "urban space" in which impervious surfaces account for $\geq 20\%$ of each pixel. This includes areas where people reside or work (e.g. single-family housing units or commercial buildings).

For each birth, we defined land-use exposure as the proportion of each land-use (urban, urban open, or green) within 250 m from residence at time of birth. The 250 m buffer size (i.e. circle with 250 m radius) was determined by literature review,(Dadvand et al., 2012b; Markevych et al., 2014) with other distances explored as sensitivity analysis. Supplementary Figure 1 shows a land-use map and example of residential locations with 250 m buffer.

2.3. Statistical analysis

Linear mixed effects models were conducted for birth weight and logistic mixed effects models for LBW and SGA. Census block group was used for random intercepts. We explored the effect of urban space, urban open space, and green space in separate models; the fraction of each land-use in the buffer around the residence was included in each model. Other included variables were: sex; gestational week; maternal age, race/ethnicity, education attainment, and marital status; trimester care started; alcohol consumption and smoking status during pregnancy; birth order (first or later); birth season; birth year; neighborhood SES variables; and average apparent temperature of each trimester, which represents overall temperature discomfort.(Kalkstein and Valimont, 1986) These variables were used in previous studies of air pollution and birth outcomes.(Ebisu et al., 2014; Ebisu and Bell, 2012) Effect estimates were calculated per interquartile range (IQR) increase of each land-use with the corresponding buffer.

2.4. Sensitivity analysis

Several sensitivity analyses were conducted. We explored alternate buffer sizes (100, 500, 1000, and 2000 m) in comparison to the original 250 m. Second, environmental variables were added in the model: PM with aerodynamic diameter ≤ 2.5 μm ($PM_{2.5}$) and traffic density. These variables were considered as environmental variables, because $PM_{2.5}$ comes from multiple sources (emission from power plant, traffic, etc.) and traffic emission contains multiple pollutants (e.g. NO_2, CO, etc.).

Gestational average of $PM_{2.5}$ was calculated based on infants' birth date and gestational length. $PM_{2.5}$ values for each birth were assigned from the nearest $PM_{2.5}$ monitor, operated by the U.S. Environmental Protection Agency. Twenty-five monitors were available in the study area and adjacent areas. The average distance between residence at birth and $PM_{2.5}$ monitor was 11.2 km. Further description of exposure estimation is available elsewhere. (Ebisu and Bell, 2012)

We used traffic data for 2000-2006 obtained through Connecticut Department of Transportation. Data consist of the annual average daily traffic (AADT) passing through interstate and numbered highways. Traffic exposure was estimated using AADT and length of highway segments around residence. We defined traffic exposure, traffic density, as the sum of AADT multiplied by the total length of the corresponding highways within 2 km of residence, divided by the area (i.e., size of circle with 2 km radius) with using weighted average of AADT data of birth year and the previous year. Buffer with 2 km was used because 1) traffic data was only available for highways, resulting in few subjects within 250 m of a highway), and 2) previous study found traffic exposure was associated with wheeze symptoms with this buffer size.(Holford et al., 2010)

We investigated whether associations differ by degrees of urbanicity. We divided the "urban space" category into low and high developed space, with impervious surfaces accounting for 20 to 49% and ≥50% of each pixel, respectively. We examined how the degree of urbanicity affects outcomes using these two variables in separate models.

Several studies revealed that land-use impacts differ by race/ethnicity and/or SES; infants born from minority or lower SES mothers are associated with higher benefits from green space.(Dadvand et al., 2012a; Ebisu et al., 2011) To investigate whether specific subpopulations have different health associations with land-use, we included an interaction term between land-use and race/ethnicity or SES (maternal race, education, and marital status). For all sensitivity analysis, we explored associations between green or urban space and three variables related to birth outcomes (i.e. birth weight, LBW, and SGA).

3. Results

After removing subjects that did not meet inclusion criteria, our study had 239,811 infants. Summary of demographic and SES variables of infants and mothers is available in Table 1. About 65% of mothers were White, and over half of mothers had at least a high school education. These distributions were similar to those for previous studies in this area.(Ebisu et al., 2014; Pereira et al., 2014) Summary statistics of primary explanatory variables (land-use within a 250 m from residence at time of birth, gestational exposure of $PM_{2.5}$ and traffic exposures) are shown in Table 2. Green and urban spaces within 250 m buffer from residence were negatively but not perfectly correlated: correlation coefficient (r) =−0.88. Urban space and traffic density were moderately correlated (r =0.54).

Green space showed protective associations with birth weight and LBW. An IQR increase in the fraction of green space within a 250 m buffer (fraction=0.38), which is about 0.07 km^2 (18.4 acre), was associated with increasing birth weight by 3.2 g (95% Confidence Interval

(CI) [0.4, 6.0]). An IQR increase in green space was associated with 7.6% [2.6, 12.4] decreased risk of LBW (Table 3). Urban space was associated with all three outcomes. An IQR increase of urban space fraction within a 250 m buffer (fraction=0.58; 0.11km^2 (28.1 acre)) was associated with lower birth weight by 5.9 g [1.6, 10.2], 16.2% [7.8, 25.3] increased risk of LBW, and 6.5% [2.6, 10.5] increased risk of SGA. Urban open space showed protective associations with LBW and SGA, while CI of the association with birth weight included zero. Census block group was used for random intercepts, and these findings were robust to models using Census tract for random intercept and models without random intercept (results not shown).

In sensitivity analysis with different buffer sizes, overall green space showed robust results across different buffer sizes, although results for several buffers were attenuated compared to results for a buffer of 250 m (Figure 1). Associations with land-use were generally robust for LBW and SGA after inclusion of variables for $PM_{2.5}$ and/or traffic density (using the original 250 m buffer), while effect estimates of land-use for birth weight slightly attenuated (Table 4).

When urban space was divided into two categories, high developed space was associated with all three outcomes, while low developed space was not (Table 3). We did not observe effect modification by race/ethnicity and SES for any outcomes (Supplementary Table 1). Results of green space showed that the less educational attainment, the more protective association with birth weight and LBW, but results failed to reach significant levels.

4. Discussion

To the best of our knowledge, this is the first study exploring land-use in relation to birth weight outcomes in the eastern U.S. Our results indicated that higher green space was associated with higher birth weight and decreased risk of LBW and SGA. This finding is consistent with other studies. For instance, a study in Israel found protective associations of green space on birth weight and LBW.(Agay-Shay et al., 2014) Tree-canopy around residence showed a protective association with SGA in Portland, Oregon.(Donovan et al., 2011) There are various possible interpretations of these results. For instance, people with more green space around residence had better self-perceived health,(Maas et al., 2006) which may be applicable for pregnant women. Moreover, increasing green space might increase maternal physical activity, which could increase birth weight.(Dadvand et al., 2012a) Living in more green space could reduce prenatal psychological stress, which was associated with LBW.(Markevych et al., 2014; Takito and Benicio, 2010) Forests in green space can absorb pollution and improve air quality,(Nowak et al., 2014) and the effect of heat can be modified by green space.(Jenerette et al., 2011) Dadvand et al. pointed out that exposure to green space is more associated with fetal growth (e.g. LBW, SGA) than with gestational length (e.g. preterm birth).(Dadvand et al., 2012b)

In addition, we observed association between urban space and birth weight, especially in high developed space. For instance, an interquartile range increment of urban space was associated with 16.2% [7.8, 25.3] increased risk of LBW. The effect estimate was similar for high developed space (16.8 [7.7, 26.8]), but not for low developed space (1.6 [−3.5, 7.0]).

One interpretation is that the fraction of urban space around residence represents the ambient pollution level: the more urban space, the more anthropogenic sources of air pollution. Our sensitivity analysis, however, showed that land-use results were generally robust after controlling for $PM_{2.5}$ and/or traffic, except associations with birth weight adjusted by $PM_{2.5}$ for both green and urban space and association with SGA adjusted by $PM_{2.5}$ for green space: these associations turned from significant to marginally significant. These results indicating that the influence of land-use on birth outcomes incorporates factors in addition to the contributions of ambient pollution. Noise, which is tied to urban environment, may partially explain effects of urbanicity. Gehring et al. reported associations between noise and birth weight after controlling for air pollution levels.(Gehring et al., 2014) Noise could contribute to maternal sleep disturbance, resulting in mental stress, which could affect fetal growth.(Ristovska and Lekaviciute, 2013) Another urban-related factor is higher temperature. Exposure to intensive heat can lead to dehydration, which decrease blood flow and eventually prevent nutrition transfer.(Stan et al., 2002) Our model was adjusted by apparent temperature, but this differs from a heat wave. Heat waves are defined as consecutive days of high temperature and address short-term extreme heat exposure, while we adjusted average of apparent temperature during gestation.

The role of green space may reflect the reverse role of urban space, given high correlation between urbanicity and greenness ($r=-0.88$) in our study area. It should be noted, however, that different mechanisms may play a role for how urban and green space environments impact health. Degree of green space may relate to beneficial mental condition, physical activity etc., while degree of urban space may integrate urban-related activity (pollution, noise, etc.). Multiple mechanisms likely occur simultaneously, and it is difficult to disentangle the degree to which green space brings beneficial effects and urban space induces adverse outcomes. Future work could be conducted to explore urban-specific and greenness-specific health effects.

Beyond our findings, other health outcomes can be related to land-use. Numerous advantages to health can be related to urbanization such as better access to health care, community involvement, etc.(Godfrey and Julien, 2005) Similarly, greenness-related factors (e.g. pollen, pesticide) might trigger adverse health outcomes. Further studies are warranted to account for the full public health impacts, both benefits and disadvantages, of urban and green spaces.

Our results did not provide strong evidence of effect modification by maternal race and SES. A recent study in U.K. found that effects of greenness near residences on birth weight are not statistically different for persons of White British or Pakistani origin.(Dadvand et al., 2014) Our ability to investigate race/ethnicity is somewhat limited by the demographic distribution of our study population. The study population was primarily White, with 5.8 and 3.7 times more infants of White mothers than African American or Hispanic mothers, respectively. Therefore, we may not have enough sample size for identifying effect modifications. Furthermore, the minority populations were more likely to live in urban regions with 7 and 10% of African American and Hispanic mothers residing in suburban and rural regions, respectively, compared to approximately 29% of White mothers

(Supplementary Figure 2). Thus, the study population has less variation in terms of green/urban exposures for minority populations.

A limitation of this study is the possibility of land-use misclassification. We used the NLCD 2001, in which each pixel is assigned a unique land-use. Multiple land-uses likely exist in a single pixel. This is particularly true for urban open space, where lawn grass and constructed materials co-exist. However, a study reported that accuracy of forest land-use is 87.0%, cultivated land is 82.0%, and urban land-use is 95.8% in New England,(Wickham et al., 2010) which suggests minimal exposure misclassification. A future study could compare our results with Normalized Difference Vegetation Index (NDVI), which assigns continuous greenness value to each pixel, resulting in different definition of greenness and urbanicity.

Another limitation is the estimation of exposure based on the address at birth; mothers could move during pregnancy. A literature review found that most mothers moved short distances during pregnancy.(Bell and Belanger, 2012) Furthermore, we did not adjust for ambient pollutants other than $PM_{2.5}$ because of the sparse ambient air monitoring network in the study area, and because some pollutants, such as NO_2, disperse quickly over short distances.(Holford et al., 2010) Combining pollutant prediction models from land-use regression or satellite image could address other air pollutants in future work.(Holford et al., 2010; Hystad et al., 2014) In addition, future studies could control for other factors related to urban environments such as stress levels, but these data would require an extensive cohort study.

In conclusion, our results suggest benefits of green space, and conversely harms from urbanicity, on birth outcomes. Reducing urban space and/or increasing green space (e.g. the greening of city environments) may increase birth weight and decrease risk of LBW and SGA. Populations living in urban environments will grow in the next half century, and allocation of green space among urban areas may play a critical role for public health in urban planning. Policy makers could consider these built environment factors in the development of urban areas, and indeed, the Food and Agriculture Organization plans to publish guidelines for promoting urban and peri-urban (i.e. around urban area) forestry.(United Nations Food and Agriculture Organisation, 2011) This study and further studies, exploring land-use effects on other health outcomes, could aid the development of such guidelines.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

SES	socio-economic status
NO_2	nitrogen dioxide
$PM_{2.5}$	particulate matter with aerodynamic diameter ≤2.5 μm
LBW	low birth weight
SGA	small for gestational age
IQR	interquartile range

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Highlights

- We explored green and urban land-use effects on birth weight in Connecticut, U.S.
- Green and urban spaces are associated with birth weight.
- Associations are generally robust after controlling for air pollution and traffic exposures.
- Our findings encourage policy makers to consider built environment factors.

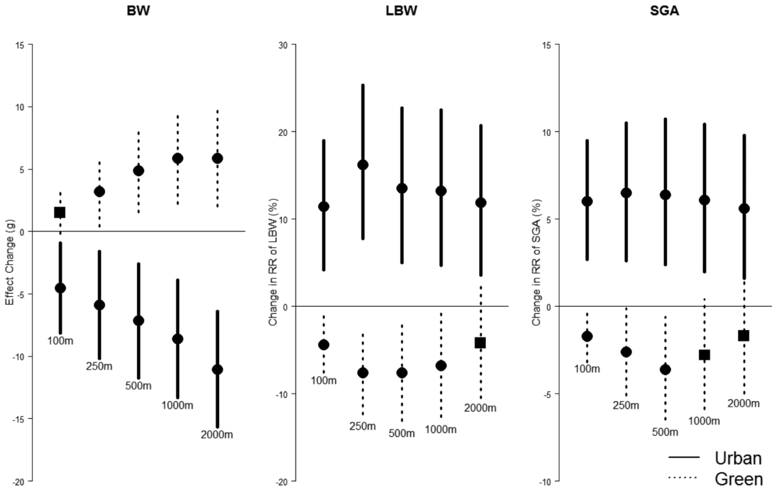

Figure 1. Associations between land-use and birth weight per IQR increase in urban or green space with different buffer sizes

Effect estimates are gram for birth weight and percent change for LBW and SGA. Land-use effect estimates are per IQR increase of corresponding buffer size (Table 2). Dots represent point estimates, and vertical lines show the 95% confidence intervals. Black circles indicate p-value <0.05, and black square shows p-value ≥0.05. Each model includes a single land-use variable and covariates.

Table 1

Summary statistics of mothers and infants (n= 239,811)

Variable		Frequency (%) or Mean (S.D.)
Birth Weight (g)		3442.1 (463.5)
Term Low Birth Weight		4,547 (1.90%)
Small for Gestational Age		20,507 (8.55%)
Sex	Male	122,037 (50.89%)
	Female	117,774 (49.11%)
Gestational Weeks	37-38 weeks	63,567 (26.51%)
	39-40 weeks	147,454 (61.49%)
	41-44 weeks	28,790 (12.01%)
Maternal Age	< 20 years	16,757 (6.99%)
	20-24 years	39,863 (16.62%)
	25-29 years	57,460 (23.96%)
	30-34 years	74,604 (31.11%)
	35-39 years	42,304 (17.64%)
	≥ 40 years	8,823 (3.68%)
Maternal Race/Ethnicity	White	156,172 (65.12%)
	African American	26,917 (11.22%)
	Asian	10,876 (4.54%)
	Hispanic	42,645 (17.78%)
	Other	3,201 (1.33%)
Maternal Education Attainment	Less than High School	28,714 (11.97%)
	High School	61,370 (25.59%)
	Some College	52,163 (21.75%)
	College	95,564 (39.85%)
	Unknown	2,000 (0.83%)
Maternal Marital Status	Married	167,536 (69.86%)
	Unmarried	72,246 (30.13%)
	Unknown	29 (0.01%)
Trimester Prenatal Care Began	1st Trimester	211,172 (88.06%)
	2nd Trimester	23,906 (9.97%)
	3rd Trimester	3277 (1.37%)
	Unknown	1,456 (0.61%)
Alcohol Consumption During Pregnancy	Yes	960 (0.40%)
	No	238,505 (99.46%)
	Unknown	346 (0.14%)

Variable		**Frequency (%) or Mean (S.D.)**
Tobacco Consumption During Pregnancy	Yes	14,477 (6.04%)
	No	224,767 (93.73%)
	Unknown	567 (0.24%)
Birth Order	First	100,601 (41.95%)
	Second or after	137,476 (57.33%)
	Unknown	1,734 (0.72%)
Birth Season	Winter	56,221 (23.44%)
	Spring	60,910 (25.40%)
	Summer	62,867 (26.22%)
	Fall	59,813 (24.94%)
Birth Year	2000	34,464 (14.37%)
	2001	34,817 (14.52%)
	2002	33,897 (14.13%)
	2003	34,871 (14.54%)
	2004	33,938 (14.15%)
	2005	33,658 (14.04%)
	2006	34,166 (14.25%)
Neighborhood Socioeconomic Status	Percentage of Less than High School Education Attainment	14.0 (11.4)
	Percentage of Below Poverty Line	10.8 (11.8)
	Percentage of Unemployment	7.0 (5.1)
Apparent Temperature	First Trimester (°F)	58.4 (38.2)
	Second Trimester (°F)	57.5 (37.9)
	Third Trimester (°F)	59.3 (38.4)

Table 2

Summary statistics of land-use, $PM_{2.5}$, and traffic density during gestation (*n*=239,811)

	Fraction of land-use within 250m of residence						
	Green Space	**Urban Open Space**	**Urban Space (high + low developed space)**	**High Developed Space**	**Low Developed Space**	**$PM_{2.5}$ (μg/m^3)**	**Traffic Density (1,000 vehicle/km)**
Mean (Standard Deviation)	0.22 (0.29)	0.16 (0.15)	0.60 (0.34)	0.37 (0.33)	0.23 (0.16)	12.4 (1.4)	21.7 (19.9)
Inter Quartile Range	0.38	0.18	0.58	0.61	0.24	1.66	30.9
Correlation							
Green Space		−0.04	−0.88	−0.69	−0.45	−0.11	−0.47
Urban Open Space			−0.39	−0.55	0.31	0.01	−0.22
Urban Space				0.89	0.29	0.11	0.54
High Developed Space					−0.18	0.10	0.55
Low Developed Space						0.03	0.01
$PM_{2.5}$							0.13

[a] Exposures estimates are based on the fraction of land-use within a 250 m buffer from residence at birth, $PM_{2.5}$ gestational exposure using the closest EPA monitor, and traffic density within a 2km buffer from residence at birth.

Table 3

Change in birth outcomes per IQR increase in land-use (95% confidence interval)

	Birth Weight (g)[a]	LBW (%)[a]	SGA (%)[a]
Green Space	3.2 (0.4, 6.0)	−7.6 (−12.4, −2.6)	−2.6 (−5.1, −0.1)
Urban Open Space	0.8 (−1.8, 3.4)	−5.7 (−10.2, −1.0)	−3.5 (−5.7, −1.2)
Urban Space	−5.9 (−10.2, −1.6)	16.2 (7.8, 25.3)	6.5 (2.6, 10.5)
High Developed Space	−5.8 (−11.0, −0.6)	16.8 (7.7, 26.8)	5.9 (1.5, 10.4)
Low Developed Space	−2.1 (−5.1, 0.8)	1.6 (−3.5, 7.0)	1.9 (−0.7, 4.6)

[a] Effect estimates are gram for birth weight and percent change for LBW and SGA. Estimates are based on the IQR increase for land-use (Table 2). Models are adjusted by sex, gestational week, maternal age, race/ethnicity, education attainment, marital status, trimester care started, alcohol consumption and smoking status during pregnancy, birth order (first or later), birth season, birth year, neighborhood SES variables (percent of less than high school education, unemployment, and below poverty line in residential census tract), and average apparent temperature of each trimester.

Table 4

Change in birth outcomes per IQR increase in land-use, adjusted by $PM_{2.5}$ and traffic density (95% confidence interval)

		Adjusted Pollutant	
	Land-use Effect[a]	$PM_{2.5}$ Effect[a]	Traffic Effect[a]
Green Space			
Birth Weight (g)	3.2 (0.4, 6.0)		
	2.0 (−0.8, 4.8)	−8.5 (−11.2, −5.8)	
	3.7 (0.7, 6.6)		1.8 (−2.0, 5.7)
	2.7 (−0.3, 5.6)	−8.7 (−11.4, −6.0)	3.0 (−0.8, 6.8)
LBW (%)	−7.6 (−12.4, −2.6)		
	−6.6 (−11.4, −1.5)	5.6 (0.9, 10.4)	
	−8.4 (−13.3, −3.2)		−3.0 (−8.3, 2.7)
	−7.5 (−12.5, −2.2)	5.8 (1.2, 10.7)	−3.6 (−8.9, 2.1)
SGA (%)	−2.6 (−5.1, −0.1)		
	−1.8 (−4.3, 0.8)	5.1 (2.8, 7.5)	
	−3.8 (−6.3, −1.2)		−4.5 (−7.3, −1.6)
	−3.1 (−5.6, −0.5)	5.6 (3.2, 8.0)	−5.1 (−7.9, −2.2)
Urban Space			
Birth Weight (g)	−5.9 (−10.2, −1.6)		
	−3.9 (−8.2, 0.4)	−8.4 (−11.1, −5.7)	
	−6.8 (−11.4, −2.3)		2.4 (−1.5, 6.2)
	−5.3 (−9.8, −0.7)	−8.6 (−11.3, −5.9)	3.4 (−0.4, 7.3)
LBW (%)	16.2 (7.8, 25.3)		
	14.4 (5.9, 23.5)	5.1 (0.5, 9.9)	
	18.5 (9.4, 28.3)		−4.3 (−9.7, 1.3)
	16.8 (7.8, 26.6)	5.4 (0.8, 10.3)	−4.8 (−10.1, 0.8)
SGA (%)	6.5 (2.6, 10.5)		
	5.1 (1.2, 9.1)	4.9 (2.5, 7.3)	
	9.1 (4.8, 13.4)		−5.4 (−8.2, −2.5)
	7.8 (3.6, 12.2)	5.3 (3.0, 7.7)	−5.9 (−8.7, −3.0)

[a] Effect estimates are gram for birth weight and percent change for LBW and SGA. Estimates are based on the IQR increase of land-use, $PM_{2.5}$, or traffic (Table 2).