



## Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status



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### ABSTRACT

Evidence of the impact of green spaces on pregnancy outcomes is limited with no report on how this impact might vary by ethnicity. We investigated the association between residential surrounding greenness and proximity to green spaces and birth weight and explored the modification of this association by ethnicity and indicators of individual (maternal education) and neighbourhood (Index of Multiple Deprivation) socioeconomic status. Our study was based on 10,780 singleton live-births from the Born in Bradford cohort, UK (2007–2010). We defined residential surrounding greenness as average of satellite-based Normalized Difference Vegetation Index (NDVI) in buffers of 50 m, 100 m, 250 m, 500 m and 1000 m around each maternal home address. Residential proximity to green spaces was defined as living within 300 m of a green space with an area of  $\geq 5000 \text{ m}^2$ . We utilized mixed effects models to estimate adjusted change in birth weight associated with residential surrounding greenness as well as proximity to green spaces. We found a positive association between birth weight and residential surrounding greenness. Furthermore, we observed an interaction between ethnicity and residential surrounding greenness in that for White British participants there was a positive association between birth weight and residential surrounding greenness whereas for participants of Pakistani origin there was no such an association. For surrounding greenness in larger buffers (500 m and 1000 m) there were some indications of stronger associations for participants with lower education and those living in more deprived neighbourhoods which were not replicated for surrounding greenness in smaller buffer sizes (i.e. 50 m, 100 m, and 250 m). The findings for residential proximity to a green space were not conclusive. Our study showed that residential surrounding greenness is associated with better foetal growth and this association could vary between different ethnic and socioeconomic groups.

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### 1. Introduction

Contact with green spaces has been shown to improve both perceived and objective physical and mental health and well-being (Bowler et al., 2010; Lee and Maheswaran, 2011). More recently, a

limited number of studies have reported beneficial impacts of green spaces on pregnancy outcomes (Dadvand et al., 2012a, 2012c; Donovan et al., 2011; Laurent et al., 2013; Markevych et al., 2014). These studies reported some benefits of maternal residential surrounding greenness for foetal growth, reflected by higher birth weight and head circumference and lower risk of low birth weight and small for gestational age (Dadvand et al., 2012a, 2012c; Donovan et al., 2011; Laurent et al., 2013; Markevych et al., 2014).

Socioeconomic inequality in health has been shown to have a multi-level structure in that individual and neighbourhood socioeconomic status (SES) could have independent associations with the susceptibility of individuals to disease (Pickett and Pearl, 2001; Ross and Mirowsky, 2008). A growing body of evidence has reported that individual SES can modify the health benefits of green spaces (De Vries et al., 2003;

*Abbreviations:* BiB, Born in Bradford; EOSDIS, Earth Observing System Data and Information System; IMD, Index of Multiple Deprivation; NDVI, Normalized Difference Vegetation Index; LSOA, lower level super output area; PHENOTYPE, Positive Health Effects of the Natural Outdoor Environment in Typical Populations of Different Regions in Europe;  $\text{PM}_{2.5}$ , particulate matter with aerodynamic diameter  $\leq 2.5 \mu\text{m}$ ; SES, socioeconomic status; TM, thematic mapper.

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Maas et al., 2009). In our previous studies of the impact of green spaces on pregnancy outcomes (Dadvand et al., 2012a, 2012c), we observed a larger benefit of green spaces for pregnant women with lower education qualifications (Dadvand et al., 2012a, 2012c). In this context, neighbourhood SES could also have a potential modifying effect on the association between green spaces and health.

The available studies on the potential modifying effect of ethnicity on health benefits of green spaces are scarce but suggestive of such an effect (Agyemang et al., 2007; Lee and Maheswaran, 2011). To our knowledge, there is no reported study on the modification of the association between green spaces and pregnancy outcomes by ethnicity.

This study aimed to investigate the association between contact with green spaces (in terms of residential surrounding greenness and proximity to green spaces) and foetal growth (in terms of birth weight) and to explore how this association might be modified by ethnicity and indicators of individual and neighbourhood SES.

## 2. Materials and methods

### 2.1. Study population

This analysis was carried out as part of the Born in Bradford (BiB) study which has been described in detail elsewhere (Wright et al., 2013). Briefly, BiB is a longitudinal multiethnic community birth cohort study aiming to examine the impact of environmental, psychological and genetic factors on maternal and child health and wellbeing (Wright et al., 2013). Participants were pregnant women at 26–28 week gestation who registered at the Bradford Royal Infirmary. For those consenting, the baseline questionnaire detailing information on socio-economic characteristics, ethnicity and family trees, lifestyle factors, environmental risk factors and physical and mental health was collected via an interview conducted in English, Mirpuri (a spoken variant of Punjabi) or Urdu.

The full BiB cohort recruited 12,453 women with 13,776 pregnancies who were receiving care from the city's maternity unit between 2007 and 2010, representing 54% of total Births during this time period (Wright et al., 2013). Compared with women who were not recruited, those in the BiB cohort had a lower proportion of younger ages (age: 20–24 years) and a higher proportion of South Asian origin and nulliparous women (Wright et al., 2013). Furthermore, those women recruited in the cohort tended to reside in slightly less deprived neighbourhoods (i.e. lower Index of Multiple Deprivation (IMD) scores described in Section 2.4.1) compared with those not recruited. This analysis included live-born singleton births with mothers who had completed the baseline questionnaire and had data available on birth outcomes (i.e. birth weight and gestational age at delivery), maternal ethnicity, and education.

Ethical approval for the data collection was granted by Bradford Research Ethics Committee (Ref 07/H1302/112).

### 2.2. Outcome measurement

Birth weight was recorded immediately after birth by the participant's midwife and was subsequently abstracted from medical records.

### 2.3. Exposure measurement

The exposure assessment of this study was carried out in the context of Positive Health Effects of the Natural Outdoor Environment in Typical Populations of Different Regions in Europe (PHENOTYPE) (Nieuwenhuijsen et al., 2014). The PHENOTYPE project aims at investigating the interconnections between exposure to natural outdoor environments and better human health and well-being across different parts of Europe. In this context, the PHENOTYPE project explores potential underlying mechanisms at work and examines the health impacts for different population groups (e.g. pregnant women and/or foetus, different age groups, socioeconomic status, ethnic minorities and patients).

We used residential surrounding greenness as a surrogate for general outdoor greenness of the living environment of study participants. To measure surrounding greenness, we applied the Normalized Difference Vegetation Index (NDVI) (Weier and Herring, 2011) derived from the Landsat 4–5 Thematic Mapper (TM) images at 30 m × 30 m resolution (US Geology Survey, 2011). NDVI is an indicator of greenness based on land surface reflectance of visible (red) and near-infrared parts of spectrum (Weier and Herring, 2011). It ranges between –1 and 1 with higher numbers indicating more greenness. To achieve maximum exposure contrast, we looked for available cloud-free Landsat TM images during the period between May and August (i.e. the maximum vegetation period of the year for our study region) of 2006–2011 (the relevant years to our study period) from the NASA's Earth Observing System Data and Information System (EOSDIS) website. Based on this search we generated our NDVI map using the image obtained on 10th June 2006 (Supplementary Fig. S1).

Each maternal address of residence was coordinated on the National Grid, with eastings and northings quoted to a resolution of 0.1 m. This was done for addresses where we found an exact match either 'automatic' or 'manually' with only a tiny percentage (0.01%) of the addresses for which we could not find a match. For each woman, surrounding greenness was abstracted as the average of NDVI in buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m around her geocoded address of residence at the time of recruitment (Dadvand et al., 2012a, 2012b, 2012c; Donovan et al., 2011; Laurent et al., 2013; Lovasi et al., 2011, 2013; Markevych et al., 2014). We used different buffer sizes to abstract residential surrounding greenness in order to explore the consistency of our findings across different buffer sizes and robustness of our findings to our selection of buffer size. Furthermore, we hypothesized that immediate surrounding greenness (e.g. in a 50 m or 100 m buffer) could be more relevant to mechanisms like psychological restoration (because of visual access to greenness) and reduction in environmental exposure (e.g. air pollution, heat, and noise); whereas, greenness in larger buffer sizes could be more associated with other mechanisms like increase in physical activity. These measures of residential surrounding greenness using NDVI has been shown to strongly correlate with perception of the greenness of corresponding residential areas (Rheu et al., 2011) and be associated with more use of green spaces and physical activity (Almanza et al., 2012; Grigsby-Toussaint et al., 2011).

### 2.4. Regression models

#### 2.4.1. Main effect

In our dataset, there were 784 women with two pregnancies and 15 with three pregnancies included in the main effect analyses. To account for this, we constructed mixed effects models with the study participants as the random effect, birth weight as the outcome, and residential surrounding greenness as the predictor. The analyses were adjusted for gestational age at delivery (weeks, linear, quadratic and cubic terms), maternal age (<20, 20–25, 25–30, 30–35, 35–40, >40 years old), ethnicity (White British, Pakistani, other), education (less than five GCSEs, Five GCSE or A level equivalent, higher than A level equivalent, other), body mass index, tobacco smoking during pregnancy (yes, no), exposure to environmental tobacco smoke during pregnancy (yes, no), neighbourhood SES, parity (zero, one, two or more), alcohol consumption during pregnancy (yes, no), parity, conception year, and conception season (spring, summer, autumn, or winter).

We used maternal education as a surrogate measure of individual SES as it has been shown to be a main determinant of pregnancy outcomes that reliably correlates with other measures of SES and has been widely used in perinatal studies (Woodruff et al., 2010). We applied the tertiles of the Index of Multiple Deprivation 2010 (IMD 2010) at lower level super output area (LSOA) level as an indicator of neighbourhood SES (McLennan et al., 2011). In the UK census, Output Areas are the lowest geographical level for reporting census statistics.

LSOAs are generated by merging Output Areas (typically four to six Output Areas) while taking measures of proximity and social homogeneity into account. For the Census of 2011, LSOAs in England and Wales on average had 672 households with a population of 1614 (Office for National Statistics, 2012). IMD is based on seven domains, namely income deprivation, employment deprivation, health deprivation and disability, education skills and training deprivation, barriers to housing and services, living environment deprivation, and crime (McLennan et al., 2011). The score for each domain is calculated from a number of indicators (38 indicators in total) and the IMD score is then abstracted by weighted aggregation of these domain scores (McLennan et al., 2011).

To facilitate the comparison of estimated associations for the surrounding greenness across different buffer sizes, we reported the results for one inter-quartile range (IQR) increase in average NDVI in each buffer size based on all study population.

#### 2.4.2. Effect modification by ethnicity, individual, and neighbourhood SES

We first checked the statistical significance of the multiplicative interaction term of residential surrounding greenness with ethnicity, maternal education, and tertiles of IMD (one at a time) by comparing fully-adjusted models with and without interaction term using likelihood ratio test. We then stratified the fully-adjusted models (as described in Section 2.4.1) separately by ethnicity, maternal education, and neighbourhood SES.

#### 2.4.3. Associations with access to green space

We explored the association between residential proximity to green spaces (a surrogate for access to green spaces (Expert Group on the urban environment, 2001)) and birth weight. According to the European Commission recommendation for access to green spaces we defined residential proximity to green spaces as living within 300 m of a green space with an area of equal or more than 5000 m<sup>2</sup> (Expert Group on the urban environment, 2001). We used Urban Atlas (UK2011-Leeds, 2006) map (European Environment Agency, 2007) to identify green spaces with an area of equal or more than 5000 m<sup>2</sup>. The satellite images used for developing Urban Atlas maps had a resolution of 1:12,000 and the map the maps present elements with areas  $\geq 2$  500 m<sup>2</sup>. We repeated the main effect analysis (as described in Section 2.4.1) using the indicator of residential proximity to a green space as the exposure variable instead of residential surrounding greenness.

### 3. Results

#### 3.1. Study population

Of 11,396 pregnancies with completed baseline questionnaires, 62 were stillbirth, 142 were multiple pregnancies, 345 did not have data on birth weight or gestational age at delivery, 49 were missing data on ethnicity, and 30 had missing data on education who were excluded from the analyses. Consequently, there were 10,780 pregnancies available for the analyses. Description of the characteristics of all included pregnancies as well as each ethnic category are presented in Table 1. While the pattern of education level was similar in participants of White British and Pakistani origin, White British participants tended to reside in less deprived neighbourhoods compared with those of Pakistani origin (Table 1). The median birth weight for White British participants was higher (Wilcoxon rank-sum test  $p$ -value  $< 0.001$ ) than that of participants with Pakistani origin (Table 2). Participants with lower educational qualifications and those residing in the most deprived neighbourhoods had generally lower birth weight (trend test  $p$ -values  $< 0.001$ ) (Table 2). The polychoric correlation coefficient between tertiles of IMD score and maternal education was  $-0.22$  suggesting that participants with lower educational qualifications generally resided in more deprived neighbourhoods.

#### 3.2. Residential surrounding greenness

The median (IQR) of the average NDVI across buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m for all participants and by strata of ethnicity, education, and neighbourhood SES are presented in Table 2. The median of residential surrounding greenness for White British participants was higher (Wilcoxon rank-sum test  $p$ -value  $< 0.001$ ) than that of participants of Pakistani origin in all buffer sizes. We observed a trend in residential surrounding greenness across strata of maternal education and neighbourhood SES with higher residential surrounding greenness (in all buffers) for participants with better education or residing in less deprived neighbourhoods (all trend test  $p$ -values  $< 0.001$ ) (Table 2). The Spearman's correlation coefficient between IMD score and residential surrounding greenness in buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m was  $-0.25$ ,  $-0.28$ ,  $-0.37$ ,  $-0.44$ , and  $-0.51$ , respectively.

#### 3.3. Regression models

##### 3.3.1. Main effect

The plots of fitted values against standardized residuals in unadjusted as well as fully-adjusted models are presented in Supplementary Fig. S2. The fully-adjusted plots suggested that the residual variance is smaller at fitted values for birth weights below 2500 g that included only a small proportion of points (7%). To account for this, we used a robust estimation of standard errors when fitting our models. In the fully-adjusted model, we observed positive associations between residential surrounding greenness and birth weight that were statistically significant for buffers of 100 m, 250 m, and 500 m and were nearly statistically significant for buffers of 50 m and 1000 m (Table 3). The estimated associations for 10% increase in average NDVI across these buffers surrounding maternal home address are presented in Supplementary Table S1.

In our dataset, there were 784 women with two pregnancies and 15 with three pregnancies included in the main effect analyses. As a sensitivity analysis, we excluded the second and third pregnancies of these women (i.e. 814 pregnancies) and conducted linear regression models with identical set of outcomes and predictors to the main effect analyses. As presented in Supplementary Table S2, the results of this sensitivity analysis were in line with those of main effect analyses; however the associations were slightly stronger in this sensitivity analyses compared to those of main effect analyses.

##### 3.3.2. Effect modification by ethnicity, individual, and neighbourhood SES

The multiplicative interaction term was statistically significant ( $p$ -value  $< 0.05$ ) for ethnicity for buffers of 250 m ( $p$ -value = 0.019), 500 m ( $p$ -value = 0.021), and 1000 m ( $p$ -value = 0.008) and nearly statistically significant for 100 m buffer ( $p$ -value: 0.089). For maternal education and for neighbourhood SES the multiplicative interaction term was not statistically significant for any of buffer sizes.

After stratifying the analysis according to ethnicity, there was a positive association between residential surrounding greenness and birth weight for offspring of White British participants (for 500 m and 1000 m buffers the associations were nearly statistically significant), whereas, the associations for participants with Pakistani origin were almost null (Table 4). For the offspring of participants classified as other ethnicity, we found a positive association between birth weight and residential surrounding greenness that were statistically significant in 250 m, 500 m, and 1000 m buffers (Table 4). This category included a wide range of ethnicities (Indians ( $N = 412$ ), Asian-other ( $N = 251$ ), white-other ( $N = 283$ ), black African ( $N = 215$ ), mixed ( $N = 166$ ), and other ( $N = 281$ )) that lacked sufficient statistical power for separate analyses.

For surrounding greenness in larger buffers of 500 m and 1000 m there was a trend in the associations across the strata of the maternal education as well as neighbourhood SES with stronger associations found for offspring of participants with lower education levels and for

**Table 1**

Characteristics of study participants. Results are presented as count (%) for categorical variables and as median (interquartile range) for continuous variables.

|                                 | Total<br>(N = 10,780) | White British<br>(N = 4283) | Pakistani Origin<br>(N = 4889) | Other Ethnic Groups<br>(N = 1608) |
|---------------------------------|-----------------------|-----------------------------|--------------------------------|-----------------------------------|
| Gestational age (week)          | 39.9 (1.9)            | 40.0 (1.9)                  | 39.7 (1.9)                     | 39.9 (2.0)                        |
| Sex                             |                       |                             |                                |                                   |
| Female                          | 5240 (48.6%)          | 2063 (48.2%)                | 2394 (49%)                     | 783 (48.7%)                       |
| Male                            | 5540 (51.4%)          | 2220 (51.8%)                | 2495 (51%)                     | 825 (51.3%)                       |
| Parity                          |                       |                             |                                |                                   |
| 0                               | 4255 (41.0%)          | 2007 (48.4%)                | 1503 (32.1%)                   | 745 (48.2%)                       |
| 1                               | 2998 (28.9%)          | 1297 (31.3%)                | 1246 (26.6%)                   | 455 (29.4%)                       |
| ≥2                              | 3118 (30.1%)          | 839 (20.3%)                 | 1934 (41.3%)                   | 345 (22.3%)                       |
| Missing                         | 409                   | 140                         | 206                            | 63                                |
| Maternal age (year)             |                       |                             |                                |                                   |
| <20                             | 592 (5.5%)            | 437 (10.2%)                 | 94 (1.9%)                      | 61 (3.8%)                         |
| ≥20 & <25                       | 2697 (25.1%)          | 1157 (27.1%)                | 1221 (25.0%)                   | 319 (19.9%)                       |
| ≥25 & <30                       | 3505 (32.6%)          | 1210 (28.3%)                | 1734 (35.5%)                   | 561 (34.9%)                       |
| ≥30 & <35                       | 2517 (23.4%)          | 884 (20.7%)                 | 1198 (24.5%)                   | 435 (27.1%)                       |
| ≥35 & 40                        | 1180 (11.0%)          | 473 (11.1%)                 | 515 (10.6%)                    | 192 (12.0%)                       |
| ≥40                             | 269 (2.5%)            | 113 (2.6%)                  | 118 (2.4%)                     | 38 (2.4%)                         |
| Missing                         | 20                    | 9                           | 9                              | 2                                 |
| Maternal education              |                       |                             |                                |                                   |
| Less than five GCSEs            | 2333 (21.6%)          | 854 (19.9%)                 | 1270 (26.0%)                   | 209 (13.0%)                       |
| Five GCSE or A level equivalent | 4880 (45.3%)          | 2188 (51.1%)                | 2144 (43.9%)                   | 548 (34.1%)                       |
| higher than A level equivalent  | 2745 (25.5%)          | 831 (19.4%)                 | 1262 (25.8%)                   | 652 (40.5%)                       |
| Other                           | 822 (7.6%)            | 410 (9.6%)                  | 213 (4.4%)                     | 199 (12.4%)                       |
| IMD score (2010)                |                       |                             |                                |                                   |
| First tertile (least deprived)  | 3530 (32.8%)          | 2060 (48.2%)                | 972 (19.9%)                    | 498 (31.1%)                       |
| Second tertile                  | 3528 (32.8%)          | 1095 (25.6%)                | 1937 (39.7%)                   | 496 (30.9%)                       |
| Third tertile (Most deprived)   | 3701 (34.4%)          | 1120 (26.2)                 | 1971 (40.4%)                   | 610 (38.0%)                       |
| Missing                         | 21                    | 8                           | 9                              | 4                                 |
| Maternal body mass index        | 27.4 (6.9)            | 27.9 (7.4)                  | 27.3 (6.5)                     | 26.8 (6.7)                        |
| Missing                         | 404                   | 133                         | 209                            | 62                                |
| Maternal alcohol consumption    |                       |                             |                                |                                   |
| No                              | 7446 (69.2%)          | 1378 (32.2%)                | 4859 (99.7%)                   | 1209 (75.4%)                      |
| Yes                             | 3307 (30.8%)          | 2898 (67.8%)                | 15 (0.3%)                      | 394 (24.6%)                       |
| Missing                         | 27                    | 7                           | 15                             | 5                                 |
| Maternal tobacco smoking        |                       |                             |                                |                                   |
| No                              | 8466 (82.2%)          | 2459 (62.4%)                | 4624 (96.2%)                   | 1383 (88.9%)                      |
| Yes                             | 1838 (17.8%)          | 1482 (37.6%)                | 184 (3.8%)                     | 172 (11.1%)                       |
| Missing                         | 476                   | 342                         | 81                             | 53                                |
| Maternal passive smoking        |                       |                             |                                |                                   |
| No                              | 7300 (68.1%)          | 2440 (57.2%)                | 3675 (75.7%)                   | 1185 (74.1%)                      |
| Yes                             | 3419 (31.9%)          | 1828 (42.8%)                | 1177 (24.3%)                   | 414 (25.9%)                       |
| Missing                         | 61                    | 15                          | 37                             | 9                                 |
| Year of conception              |                       |                             |                                |                                   |
| 2006                            | 1042 (9.7%)           | 411 (9.6%)                  | 489 (10%)                      | 142 (8.8%)                        |
| 2007                            | 2692 (25.0%)          | 1073 (25.1%)                | 1221 (25.0%)                   | 398 (24.8%)                       |
| 2008                            | 2875 (26.7%)          | 1096 (25.6%)                | 1362 (27.9%)                   | 417 (25.9%)                       |
| 2009                            | 2846 (26.4%)          | 1158 (27%)                  | 1242 (25.4%)                   | 446 (27.7%)                       |
| 2010                            | 1325 (12.3%)          | 545 (12.7%)                 | 575 (11.8%)                    | 205 (12.7%)                       |
| Season of conception            |                       |                             |                                |                                   |
| Spring                          | 2807 (26.0%)          | 1151 (26.9%)                | 1231 (25.2%)                   | 425 (26.4%)                       |
| Summer                          | 2313 (21.5%)          | 916 (21.4%)                 | 1047 (21.4%)                   | 350 (21.8%)                       |
| Autumn                          | 2833 (26.3%)          | 1079 (25.2%)                | 1330 (27.2%)                   | 424 (26.4%)                       |
| Winter                          | 2827 (26.2%)          | 1137 (26.6%)                | 1281 (26.2%)                   | 409 (25.4%)                       |

**Table 2**

Median and interquartile range (in brackets) of birth weight and average NDVI across buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m around residential addresses separately for all participants and strata of maternal ethnicity, education, and neighbourhood SES.

|                                 | Birth weight (g) | Residential surrounding greenness |              |              |              |               |
|---------------------------------|------------------|-----------------------------------|--------------|--------------|--------------|---------------|
|                                 |                  | 50 m buffer                       | 100 m Buffer | 250 m Buffer | 500 m Buffer | 1000 m buffer |
| All participants                | 3250 (660)       | 0.19 (0.17)                       | 0.21 (0.16)  | 0.23 (0.15)  | 0.25 (0.14)  | 0.26 (0.13)   |
| Maternal ethnicity              |                  |                                   |              |              |              |               |
| White British                   | 3380 (680)       | 0.25 (0.12)                       | 0.26 (0.12)  | 0.28 (0.11)  | 0.30 (0.10)  | 0.31 (0.12)   |
| Pakistani origin                | 3140 (630)       | 0.19 (0.17)                       | 0.21 (0.16)  | 0.22 (0.15)  | 0.24 (0.14)  | 0.25 (0.13)   |
| Other                           | 3220 (643)       | 0.13 (0.16)                       | 0.14 (0.15)  | 0.17 (0.14)  | 0.19 (0.13)  | 0.22 (0.09)   |
| Maternal education              |                  |                                   |              |              |              |               |
| Less than five GCSEs            | 3200 (650)       | 0.17 (0.18)                       | 0.18 (0.17)  | 0.20 (0.15)  | 0.23 (0.15)  | 0.23 (0.11)   |
| Five GCSE or A level equivalent | 3250 (660)       | 0.20 (0.17)                       | 0.21 (0.16)  | 0.23 (0.15)  | 0.26 (0.14)  | 0.26 (0.13)   |
| Higher than A level equivalent  | 3260 (680)       | 0.20 (0.16)                       | 0.22 (0.16)  | 0.24 (0.14)  | 0.27 (0.13)  | 0.27 (0.13)   |
| Other                           | 3315 (639)       | 0.22 (0.15)                       | 0.23 (0.14)  | 0.25 (0.14)  | 0.28 (0.14)  | 0.28 (0.13)   |
| Neighbourhood IMD               |                  |                                   |              |              |              |               |
| 1st quartile (least deprived)   | 3320 (680)       | 0.23 (0.11)                       | 0.25 (0.10)  | 0.28 (0.10)  | 0.30 (0.10)  | 0.32 (0.12)   |
| 2nd quartile                    | 3220 (650)       | 0.15 (0.18)                       | 0.17 (0.16)  | 0.19 (0.14)  | 0.23 (0.12)  | 0.24 (0.08)   |
| 3rd quartile (most deprived)    | 3220 (660)       | 0.16 (0.19)                       | 0.17 (0.18)  | 0.18 (0.16)  | 0.19 (0.15)  | 0.21 (0.11)   |

**Table 3**

Regression coefficients (95% confidence interval) indicating the change in birth weight (grammes) associated with one interquartile range<sup>a</sup> increase in average of NDVI in buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m around each maternal residential address.

| Models               | Residential surrounding greenness (NDVI) |              |         |              |               |         |              |               |         |              |               |         |               |               |         |
|----------------------|--|--------------|---------|--------------|---------------|---------|--------------|---------------|---------|--------------|---------------|---------|---------------|---------------|---------|
|                      | 50 m Buffer                              |              |         | 100 m Buffer |               |         | 250 m Buffer |               |         | 500 m Buffer |               |         | 1000 m Buffer |               |         |
|                      | $\beta$                                  | 95% CI       | p-Value | $\beta$      | 95% CI        | p-Value | $\beta$      | 95% CI        | p-Value | $\beta$      | 95% CI        | p-Value | $\beta$       | 95% CI        | p-Value |
| Model 1 <sup>b</sup> | 78.4                                     | (62.3, 94.6) | <0.001  | 86.2         | (70.2, 102.1) | <0.001  | 94.4         | (78.9, 109.9) | <0.001  | 96.9         | (81.5, 112.3) | <0.001  | 90.3          | (75.9, 104.6) | <0.001  |
| Model 2 <sup>c</sup> | 50.1                                     | (36.2, 64.0) | <0.001  | 53.5         | (39.7, 67.3)  | <0.001  | 54.2         | (40.9, 67.5)  | <0.001  | 56.3         | (43.0, 69.6)  | <0.001  | 53.6          | (41.2, 66.0)  | <0.001  |
| Model 3 <sup>d</sup> | 47.8                                     | (33.9, 61.7) | <0.001  | 51.0         | (37.2, 64.8)  | <0.001  | 51.7         | (38.3, 65.1)  | <0.001  | 53.8         | (40.5, 67.2)  | <0.001  | 51.3          | (38.8, 63.7)  | <0.001  |
| Model 4 <sup>e</sup> | 44.0                                     | (29.6, 58.4) | <0.001  | 47.1         | (32.7, 61.5)  | <0.001  | 47.4         | (33.3, 61.5)  | <0.001  | 49.7         | (35.2, 64.1)  | <0.001  | 48.0          | (34.1, 61.8)  | <0.001  |
| Model 5 <sup>f</sup> | 18.0                                     | (3.7, 32.3)  | 0.013   | 20.3         | (6.1, 34.6)   | 0.005   | 21.2         | (7.4, 35.1)   | 0.003   | 21.4         | (7.5, 35.3)   | 0.003   | 18.6          | (5.5, 31.8)   | 0.005   |
| Model 6 <sup>g</sup> | 14.0                                     | (-0.8, 28.7) | 0.063   | 15.8         | (1.1, 30.6)   | 0.036   | 16.2         | (1.7, 30.8)   | 0.028   | 15.8         | (0.9, 30.7)   | 0.038   | 12.7          | (-1.8, 27.2)  | 0.084   |

<sup>a</sup> 0.176 for 50 m buffer, 0.166 for 100 m buffer, 0.150 for 250 m buffer, 0.142 for 500 m buffer, and 0.127 for 1000 m buffer.

<sup>b</sup> Without any adjustment.

<sup>c</sup> Adjusted for gestational age at delivery, maternal age, body mass index, tobacco smoking during pregnancy, exposure to environmental tobacco smoke during pregnancy, parity, alcohol consumption during pregnancy, parity, conception year, and conception season.

<sup>d</sup> Adjusted for the covariates in model 2 plus maternal education.

<sup>e</sup> Adjusted for the covariates in model 2 plus tertiles of neighbourhood IMD.

<sup>f</sup> Adjusted for the covariates in model 2 plus ethnicity.

<sup>g</sup> Adjusted for the covariates in model 2 plus ethnicity and indicators of individual and neighbourhood SES.

those residing in more deprived neighbourhoods with statistically significant associations only for those residing in the most deprived neighbourhoods (Table 4). Such trends were not observed for surrounding greenness in smaller buffers of 50 m, 100 m, and 250 m; however, the associations for those residing in the most deprived neighbourhoods were the strongest and statistically significant (Table 4).

### 3.3.3. Associations with access to green space

Of 10,780 study participants, 6406 (59.4%) lived within 300 m of a green space with an area  $\geq 5000$  m<sup>2</sup>. We observed an increase in birth weight for those living within 300 m of these green spaces compared to those living further away; however the association lost its statistical significance after adjusting the analysis for relevant covariates. The regression coefficient for residential proximity to green spaces was 22.8 (95% CI: 1.26, 44.3) and 4.8 (95% CI: -12.5, 22.1) in unadjusted and fully-adjusted models respectively. We repeated this analysis using different combinations of distance (i.e. 100 m or 500 m) and area (i.e. any size or  $\geq 5000$  m<sup>2</sup>) of green spaces to define residential proximity to green spaces and did not observe any statistically significant association with birth weight.

## 4. Discussion

We studied the impact of contact with green spaces on birth weight in a well-established cohort. The ethnic composition of this cohort with about 40% of participants being White British and 45% having Pakistani origin provided a unique opportunity to investigate, for the first time, the influence of ethnicity on the beneficial impact of green spaces on pregnancy outcomes that also adds to the scarce evidence on ethnic inequality in health benefits of green spaces. This study is also one of the first to evaluate the influence of neighbourhood SES on the health benefits of green spaces. We found a positive association between residential surrounding greenness and birth weight. Furthermore, we observed an interaction between ethnicity and residential surrounding greenness in that for White British participants there was a positive association between birth weight residential surrounding greenness whereas for participants of Pakistani origin there was no such association. We also observed indications suggesting that the association between residential surrounding greenness and birth weight are stronger for more deprived individuals; however, these observations were only evident for residential surrounding greenness in larger buffer sizes. Our findings for residential proximity to a green space were not conclusive.

Our observed increase in birth weight associated with higher residential surrounding greenness is consistent with the existing literature

(Dadvand et al., 2012a, 2012c; Donovan et al., 2011; Laurent et al., 2013; Markevych et al., 2014). Donovan et al. (2011) studied the impact of tree-canopy cover surrounding maternal home address on pregnancy outcomes in the US and found a beneficial impact on foetal growth (i.e. lower risk of small for gestational age) but not for the length of gestation (Donovan et al., 2011). Our studies (2012) on the impact of green spaces on pregnancy outcomes in Spain using NDVI that takes account of all types of vegetations (and not only trees) (Dadvand et al., 2012a, 2012b) found that higher residential surrounding greenness was associated with improved indicators of foetal growth (i.e. higher birth weight and birth head circumference) but not with the length of gestation (Dadvand et al., 2012a, 2012c). Similarly, in the present study we did not observe any beneficial impact on the length of gestation (data available but not included). However, a recently published US study has shown a reduction in preterm birth and an increase in birth weight associated with higher residential surrounding greenness (Laurent et al., 2013). In one of our previous studies, we also observed some indications for a positive association between residential proximity to major green spaces and foetal growth (Dadvand et al., 2012a). In this current study, however, we did not observe such an association, consistent with findings of a German study reporting no association with the presence of green spaces in neighbourhood (Markevych et al., 2014). In our previous study, we defined major green spaces as those larger than 50,000 m<sup>2</sup> whereas for this current study, based on the definition of the European Commission for access to green spaces, we defined green spaces as those larger than 5000 m<sup>2</sup>. The size of green spaces has been reported to be among the determinants of their likelihood of being used for physical activity (McCormack et al., 2010).

The underlying mechanisms for health benefits of green spaces are not fully understood, but increasing physical activity, facilitating psychological restoration, improving social contacts, and reducing exposure to air pollution, noise, and heat have been suggested (Bowler et al., 2010; Lee and Maheswaran, 2011). Through these mechanisms, green spaces could also have an impact on pregnancy outcomes. In our previous study using personal air pollution monitors in 54 pregnant women, we observed that higher residential surrounding greenness (average NDVI in buffers of 100 m, 250 m, and 500 m) was associated with lower levels of personal exposure to particulate matter with aerodynamic diameter  $\leq 2.5$   $\mu\text{m}$  (PM<sub>2.5</sub>) (Dadvand et al., 2012b). Exposure to ambient air pollution during pregnancy has been linked with a range of adverse pregnancy outcomes including lower birth weight (Dadvand et al., 2013; Sapkota et al., 2010). Green spaces have been suggested to increase physical activity (Lachowycz and Jones, 2011), and moderate physical activity during pregnancy has been associated with better foetal growth (Both et al., 2010; Leiferman

**Table 4**  
Regression coefficients (95% confidence interval) indicating the change in birth weight (grammes) associated with one interquartile range increase<sup>a</sup> in average of NDVI in buffers of 50 m, 100 m, 250 m, 500 m, and 1000 m around each maternal residential address, separately for each stratum of maternal ethnicity, education, and neighbourhood SES.

| N                                     | Residential surrounding greenness (NDVI) |                    |                  |                    |                  |                    |                  |                    |                  |                    |                  |         |                  |         |  |
|---------------------------------------|--|--------------------|------------------|--------------------|------------------|--------------------|------------------|--------------------|------------------|--------------------|------------------|---------|------------------|---------|--|
|                                       | 50 m buffer                              |                    |                  | 100 m buffer       |                  |                    | 250 m buffer     |                    |                  | 500 m buffer       |                  |         | 1000 m buffer    |         |  |
|                                       | $\beta$ (95% CI)                         | p-Value            | $\beta$ (95% CI) | p-Value            | $\beta$ (95% CI) | p-Value            | $\beta$ (95% CI) | p-Value            | $\beta$ (95% CI) | p-Value            | $\beta$ (95% CI) | p-Value | $\beta$ (95% CI) | p-Value |  |
| <b>Ethnicity<sup>b</sup></b>          |  |                    |                  |                    |                  |                    |                  |                    |                  |                    |                  |         |                  |         |  |
| White British                         | 4238                                     | 27.2 (3.5, 50.8)   | 0.024            | 27.7 (3.8, 51.5)   | 0.023            | 26.2 (3.1, 49.3)   | 0.026            | 20.1 (-3.4, 43.1)  | 0.094            | 19.7 (-1.9, 41.3)  | 0.073            |         |                  |         |  |
| Pakistani origin                      | 4889                                     | 7.1 (-15.8, 29.9)  | 0.545            | 9.4 (-13.7, 32.5)  | 0.427            | 6.5 (-16.4, 29.5)  | 0.576            | 7.0 (-16.7, 30.8)  | 0.561            | 0.5 (-23.4, 24.4)  | 0.966            |         |                  |         |  |
| Other                                 | 1608                                     | 25.3 (-11.2, 61.8) | 0.174            | 32.3 (-3.6, 69.8)  | 0.077            | 41.3 (6.2, 76.4)   | 0.021            | 43.0 (6.8, 79.2)   | 0.020            | 36.3 (0.4, 72.3)   | 0.048            |         |                  |         |  |
| <b>Maternal education<sup>c</sup></b> |  |                    |                  |                    |                  |                    |                  |                    |                  |                    |                  |         |                  |         |  |
| Less than five GCSEs                  | 2333                                     | 11.7 (-20.3, 43.8) | 0.473            | 10.6 (-21.5, 42.7) | 0.518            | 15.1 (-16.4, 46.7) | 0.348            | 18.3 (-14.4, 51.0) | 0.272            | 22.9 (-9.4, 55.1)  | 0.164            |         |                  |         |  |
| Five GCSE or A level equivalent       | 4880                                     | 20.6 (-1.1, 42.3)  | 0.063            | 23.6 (1.6, 45.5)   | 0.035            | 19.3 (-2.1, 40.7)  | 0.076            | 18.1 (-3.9, 40.0)  | 0.106            | 15.6 (-5.3, 36.5)  | 0.145            |         |                  |         |  |
| Higher than A level equivalent        | 2745                                     | 14.5 (-14.7, 43.6) | 0.330            | 15.7 (-13.3, 44.7) | 0.288            | 17.2 (-12.6, 46.9) | 0.258            | 11.2 (-19.7, 42.0) | 0.478            | 2.3 (-28.1, 32.7)  | 0.882            |         |                  |         |  |
| Other                                 | 822                                      | 23.4 (-31.0, 77.7) | 0.399            | 25.4 (-30.0, 80.8) | 0.368            | 30.4 (-20.1, 80.9) | 0.238            | 35.3 (-14.9, 85.6) | 0.168            | 11.3 (-37.1, 59.7) | 0.647            |         |                  |         |  |
| <b>Neighbourhood IMD<sup>d</sup></b>  |  |                    |                  |                    |                  |                    |                  |                    |                  |                    |                  |         |                  |         |  |
| 1st tertile (least deprived)          | 3530                                     | 9.7 (-17.6, 37.0)  | 0.487            | 19.5 (-8.0, 47.0)  | 0.164            | 20.1 (-6.5, 46.6)  | 0.138            | 9.6 (-16.7, 35.9)  | 0.474            | 7.1 (-16.2, 30.3)  | 0.549            |         |                  |         |  |
| 2nd tertile                           | 3528                                     | 7.9 (-17.7, 33.5)  | 0.545            | 8.3 (-16.6, 33.2)  | 0.514            | 11.4 (-13.4, 36.2) | 0.369            | 15.4 (-11.7, 42.4) | 0.265            | 13.8 (-14.6, 42.2) | 0.340            |         |                  |         |  |
| 3rd tertile (most deprived)           | 3701                                     | 38.9 (13.6, 64.3)  | 0.003            | 38.1 (11.7, 64.4)  | 0.005            | 35.8 (9.9, 61.7)   | 0.007            | 39.7 (13.8, 65.5)  | 0.003            | 37.2 (11.6, 62.7)  | 0.004            |         |                  |         |  |

<sup>a</sup> 0.176 for 50 m buffer, 0.166 for 100 m buffer, 0.150 for 250 m buffer, 0.142 for 500 m buffer, and 0.127 for 1000 m buffer.

<sup>b</sup> Adjusted for gestational age at delivery, maternal age, body mass index, tobacco smoking during pregnancy, exposure to environmental tobacco smoke during pregnancy, parity, alcohol consumption during pregnancy, parity, conception year, conception season, maternal education, and neighbourhood IMD.

<sup>c</sup> Adjusted for gestational age at delivery, maternal age, body mass index, tobacco smoking during pregnancy, exposure to environmental tobacco smoke during pregnancy, parity, alcohol consumption during pregnancy, parity, conception year, conception season, maternal ethnicity, and neighbourhood IMD.

<sup>d</sup> Adjusted for gestational age at delivery, maternal age, body mass index, tobacco smoking during pregnancy, exposure to environmental tobacco smoke during pregnancy, parity, alcohol consumption during pregnancy, parity, conception year, conception season, maternal education, and ethnicity.

and Evenson, 2003) and better maternal mental health (Poudevigne and Oconnor, 2006). Maternal psychological stress and depression have been associated with decreased birth weight (Grote et al., 2010; Rondo et al., 2003) and green spaces have been reported to improve depression and facilitate psychological restoration (Bowler et al., 2010).

The available evidence on the modification of health benefits of green spaces by ethnicity is scarce and we are not aware of previous published results in pregnant women (Agyemang et al., 2007; Lee and Maheswaran, 2011). We observed a statistically significant multiplicative interaction between residential surrounding greenness and ethnicity. After we stratified the main effect analysis according to ethnicity, we observed that while there was an increased birth weight associated with higher residential surrounding greenness for White British participants, there was no such an association for those of Pakistani origin; however, the 95% confidence intervals of the associations for White British participants and those of Pakistani origin were overlapping. We also observed a positive association for participants classified as “other” ethnicity. This category included a wide range of ethnicities (Indians (3.8%), Asian-other (2.3%), white-other (2.6%), black African (2.0%), mixed (1.5%), and other (2.6%)) that lacked sufficient statistical power for separate analyses. Considering the heterogeneous nature of this category, interpretation of the results for this category is limited. Exclusion of participants classified as “other” ethnicity did not result in any notable change in the statistical significance of the multiplicative interaction term of ethnicity and residential surrounding greenness.

A potential explanation for our observed difference between participants of White British and Pakistani origin could be the difference in their use of green spaces. A recent national survey (2012–2013) on the use of natural environments in England has reported that the “black and minority ethnic” population are less likely to use natural environment compared to the white population (Natural England, 2013). A number of reasons for this have been suggested, including a lack of activities attractive to ethnic minorities, lack of suitable interpretative information and awareness for these groups, lack of confidence (e.g. fears of getting lost or vulnerability), negative feelings associated with previous experiences (e.g. perceived experience of racism), financial costs, and shortage of free time (Morris, 2003).

We observed two separable patterns in the findings of analyses of residential surrounding greenness and birth weight stratified according to maternal education and neighbourhood SES. While for surrounding greenness in smaller buffers (surrogating immediate residential surrounding greenness) we did not observe any trend across strata of maternal education and neighbourhood SES, for surrounding greenness in larger buffer sizes (surrogating neighbourhood surrounding greenness) we observed trends suggesting stronger positive associations for more deprived participants. The association attained statistical significance for those living in the most deprived neighbourhoods in all buffer sizes. These separable patterns for immediate residential surrounding greenness and neighbourhood greenness might be partly attributed to their potentially different underlying mechanisms as described in Section 2.3. These findings are also in line with our observed higher correlation between IMD scores and surrounding greenness in larger buffer sizes (described in Section 3.2). The “other” education category included three subcategories: *other qualifications* (e.g. City and Guilds, RSA/OCR, BTEC) (N = 596), *unknown foreign qualifications* (N = 106), and *not known* (N = 120). Because of variations between and within these three subcategories, interpretation of the findings of the stratified analyses for the “other” education category is limited. Our observed trend in associations for residential surrounding greenness in larger buffers across strata of maternal education is consistent with findings of our previous studies on the impact of residential surrounding greenness on birth weight showing stronger positive association for mothers with lower education (Dadvand et al., 2012a, 2012b). This trend is also in line with findings of previous studies showing greater health benefits from green spaces in individuals with less educational qualifications (De Vries et al., 2003; Maas et al., 2009).

One explanation for how benefiting from green spaces could be influenced by SES is that generally worse health status of people with lower SES who are also more probable to live in areas with more environmental problems could make them more likely to benefit from health promotion interventions (e.g. developing green spaces) compared to groups of higher SES (Bolte et al., 2010; De Vries et al., 2003; Su et al., 2011). In our study, participants with lower educational qualifications and those residing in more deprived neighbourhood tended to have less residential surrounding greenness and lower birth weight. Moreover, people with lower SES are generally less mobile than those of higher SES and tend to spend more time nearby their homes (Maas, 2008; Schwanen et al., 2002). Thus, the availability of green spaces close to their homes may increase the probability of them using these spaces (Maas, 2008; Schwanen et al., 2002). On the other hand, the green spaces farther away are more likely to be used by people with higher SES because they are more mobile (Bell et al., 2010; Greenspace Scotland, 2008) and, consequently, their use of these spaces is less dependent on having green spaces close to their homes. The larger health benefits of green spaces for lower SES groups are in line with the suggested potential role of green spaces in reducing SES inequalities in health. Some support for this was provided by Mitchell and Popham (2008) who reported that in greener neighbourhoods across England, income-related inequalities in mortality were less evident (Mitchell and Popham, 2008).

This study faced some limitations. For our main analyses, we could not rule out the likelihood of self-selection bias in that mother from higher SES or better health status being more likely to select living in greener neighbourhoods and to give birth to newborns with higher birth weight. Likewise, generalizability of our findings could have been affected by selection bias in that those women recruited in BiB cohort were different from those not recruited with respect to a number of characteristics, especially neighbourhood SES. Our application of satellite-based NDVI to assess surrounding greenness enabled us to take account of small-scale green spaces (e.g. roadside trees and home gardens) in a standardized way; however, NDVI does not distinguish between different types of vegetation. The vegetation type can be relevant to some of the proposed underlying mechanisms for health benefits of green spaces. For example, the ability of green space in reducing air pollutants is reported to be type-dependent with trees being the most effective and grasses being the least effective (Givoni, 1991). By using the NDVI map obtained at a single point of time, we effectively assumed that the spatial distribution of NDVI across our study region remained stable over the study period. As presented in Web-Appendix I in the Supplementary materials, while the amount of residential surrounding greenness changed over the seasons, its spatial contrast stayed reasonably stable over seasons and years. This stability is in line with findings of our previous study supporting the stability of the NDVI spatial contrast over seasons and years (Dadvand et al., 2012b). Lack of temporal component in our assessment of residential surrounding greenness limited our ability to explore the potential existence of relevant critical exposure window(s) (e.g. trimesters) during pregnancy. Furthermore, we did not have data on use of green spaces by our study participants, an issue that could be relevant to some of the possible mechanisms (e.g. physical activity) underlying our observed associations. Furthermore, we could not address the impact of green space quality; characteristics such as safety, aesthetics, biodiversity, walkability, sport/play facilities, and organized social events that have been suggested to affect the use of green spaces (McCormack et al., 2010). These warrant further investigation.

## 5. Conclusion

While our findings for residential proximity to green spaces were not conclusive, we observed a positive association between residential surrounding greenness and birth weight, which was evident only in White British participants and not in those of Pakistani origin. Our

findings were also suggestive for stronger associations between residential surrounding greenness in larger buffers (i.e. neighbourhood greenness) and birth weight for more deprived participants which was not evident for residential surrounding greenness in smaller buffers (i.e. immediate residential surrounding greenness). Such beneficial impacts, if established by future studies, are of public health importance because reduction in birth weight is not only associated with enhanced risk of morbidity and mortality in early life, but also is increasingly related to adverse health outcomes in later life (Balci et al., 2010; Huxley et al., 2007; White et al., 2009). Therefore, our observed associations between green spaces and foetal growth, especially among pregnant women of lower SES who are more affected by adverse pregnancy outcomes, could be incorporated in translating evidence into policies regarding development of urban green spaces and provision of such spaces in socioeconomically deprived areas in order to tackle health inequalities. Our findings, if confirmed by future studies, also highlight a need for targeted interventions to reduce the ethnic differences in which pregnant women can benefit from local natural environments. We recommend further studies on this association in other multiethnic populations with careful characterization of the quality of green spaces and investigating the possible mechanism(s) underlying this association.

## Conflict of interest

Authors declare that they have no conflicts of interests to disclose.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.envint.2014.06.010>.

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