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Social inequalities in the associations between urban green spaces, self-perceived health and mortality in Brussels: results from a census-based cohort study

Abstract

This study examines the associations between residential urban green spaces (UGS) and self-perceived health and natural cause mortality, applying an intersectional approach across gender, education and migrant background. We used data from the 2001 Belgian census linked to register data on emigration and mortality for the period 2001-2014, including 571,558 individuals aged 16-80 residing in Brussels (80% response rate). Residential UGS were assessed with the Normalised Difference Vegetation Index (NDVI) within a 300m buffer from the residential address and perceived neighbourhood greenness. Multilevel logistic and Cox proportional hazards regression models were conducted to estimate associations between UGS and poor self-perceived health at baseline and natural cause mortality during follow-up. Residential UGS were inversely associated with both outcomes, but there were differences between groups. The strongest beneficial associations among women were found in the lower educated, regardless of their migrant background. For men the strongest association was found in those with tertiary education and Belgian origin. No significant beneficial associations were found in men originating from low and middle-income countries. Applying an intersectionality approach is crucial to understand health inequalities related to UGS exposure. Further research in different geographical contexts is needed to contrast our findings.

Keywords

Green space; Built Environment; Self-perceived health; Mortality; Health inequalities.

1. Introduction

Greening strategies have been put forward as potential solutions for guaranteeing sustainability and inclusivity in cities in the light of ongoing urbanization (Eurostat, 2017). Urban green spaces (UGS) may improve the health and well-being of urban dwellers (Gascon et al., 2016, 2015; James et al., 2015; Rojas-Rueda et al., 2019; Van Den Berg et al., 2015) through the reduction of environmental hazards, increased biodiversity, stress reduction and restoration, and opportunities for physical activity and social cohesion (Nieuwenhuijsen et al., 2017). Additionally, the health effects of green spaces might strongly depend on socioeconomic and demographic factors, which are likely to determine the exposure (Rigolon, 2016) and the susceptibility and sensitivity of the population to residential UGS, as already stated for urban environmental stressors (Science for Environment Policy, 2016).

To date, the few studies investigating the effect modification of socioeconomic and demographic characteristics on the associations between UGS and health have shown inconsistent results, e.g., by gender (Astell-Burt et al., 2014a, 2014b; Reklaitiene et al., 2014; Richardson and Mitchell, 2010; Triguero-Mas et al., 2015), by socioeconomic position (SEP) (de Vries et al., 2003; Maas et al., 2009; Mitchell and Popham, 2008; Sugiyama et al., 2016; Triguero-Mas et al., 2015), and by ethnicity or migrant background (Dadvand et al., 2014; McEachan et al., 2018, 2016). A potential explanation for the incongruences observed across studies may be the focus on one single social stratification dimension (i.e., gender, SEP, or migrant background) instead of using an intersectional approach. Intersectionality is a critical social theory denouncing and studying how interweaved systems of oppression (e.g., racism, capitalism or sexism) affect individual's experiences and shape life chances, which in turn may contribute to health inequalities (Crenshaw, 1989; Green et al., 2017). In addition to exploring how health, disease and risk factors are unequally distributed across population groups defined by gender, socioeconomic position or ethnicity, intersectionality underscores the need to move beyond and understand the relational mechanisms, i.e., the systems of oppression underlying these factors (Wemrell et al., 2017). Therefore, epidemiological research focusing on a single dimension of social stratification might yield biased estimations of health inequalities (Bates et al., 2009), since aforementioned dimensions act simultaneously in producing social inequalities (Bauer, 2014). The most common way to approach intersectionality is through the categorisation of individuals into social strata resulting from the combination of different dimensions of inequality, named the inter-categorical approach (Evans, 2019a; Green et al., 2017). This method has been criticized for using rigid social positions, therefore overlooking potential heterogeneity within groups and/or overlapping of different social categories (Bauer, 2014; Wemrell et al., 2017). It is however still considered as a useful and comprehensive analytical tool to explore and enhance understandings of societal power dynamics (Green et al., 2017; Kapilashrami et al., 2015). This approach has been framed as "descriptive intersectionality", focusing on heterogeneity in health outcomes across social strata. It is contrasted with "analytic intersectionality", which aims at understanding heterogeneity in the social processes driving health inequalities (Bauer and Scheim, 2019).

Intersectionality theory aligns with advocacy for the implementation of proportionate universalism, a policy approach towards a greater emphasis of health interventions on more disadvantaged population groups (Marmot et al., 2020). Yet, although quantitative methods to approach intersectionality are rapidly evolving, and despite the importance of the living environment as a meso-level health determinant, it is rarely investigated how intersectionality varies depending on the living environment (Evans, 2019b), let alone accounting for environmental characteristics. To our knowledge, only one study on UGS and health – focusing on youth obesity – has assessed effect

modification of this association through the intersection of social characteristics (Hughey et al., 2017). Hughey et al. (Hughey et al., 2017) found that the inverse association between neighbourhood park/playground availability and body mass index (BMI) in children was moderated by SEP and ethnicity in a different way for boys and girls. In boys, beneficial effects were observed among the low-SEP group, while, in girls, this association was found among the white and the high-SEP group (Hughey et al., 2017).

In Belgium, the Brussels Capital Region (BCR) represents an interesting case to investigate social inequalities in the associations between UGS and health. The BCR is an administrative core of a broader urban agglomeration and one of the most densely populated European cities (73.5 inhabitants/hectare in 2016) (BISA (Brussels Institute of Statistics and Analysis), 2017). According to the 2015 World Migration Report, it is the second city worldwide with the highest percentage of residents of foreign origin (62%) (IOM (International Organization for Migration), 2015). Partly due to migratory dynamics within the city, there is a clear spatial differentiation between the least and the most deprived areas (Deboosere et al., 2009). Furthermore, the BCR is considered to be a green city: its 8,714 hectares of green cover account for 54% of the total area. From these, 35% are public green spaces, which account on average for 26m² per inhabitant (Brussels Environment, 2012). However, the distribution of these green spaces varies widely among residents (Van de Voorde, 2016).

In this study, we assess the associations of residential UGS indicators – both objective and subjective – with self-perceived health and natural cause mortality in the BCR, and the potential effect modification of social strata applying an intersectionality approach, i.e., incorporating three dimensions simultaneously: gender, SEP and migrant background.

2. Methods

Data design and study population

Analyses were based on the 2001 Belgian census linked to register data on mortality and emigration during a follow-up period from 1 October 2001 until 31 December 2014 (13.25 years of follow-up). Data on original causes of death issued from death certificates were coded using the 10th revision of the International Classification of Disease (ICD-10) (WHO (World Health Organization), 2016). The 2001 Belgian census contains data on self-perceived health and a wide set of sociodemographic and socioeconomic variables for the total population officially residing in Belgium at the time of the census. In Brussels, response rate was around 80%. In addition, several environmental indicators (i.e., UGS, ambient air pollution and noise) were linked to the 2001 Belgian census using the official residential address of each individual at baseline. The linkage procedure was done by a third party at Statistics Belgium (<https://statbel.fgov.be/en>) in line with all privacy norms. We included all individuals aged 16 to 80 who officially resided in the BCR according to the Belgian census 2001 and for whom information on the exact official home address was available (971 observations excluded, 0.13%) (N=571,558 individuals).

Health outcomes

Health outcomes used in this study were self-perceived health and natural cause mortality. Information on self-perceived health was obtained from the 2001 census by asking respondents to rate their general health on a five-point Likert scale. Following the methodology from previous studies, we dichotomized this variable as “good self-perceived health” (“good” or “very good”) versus “poor self-perceived health” (“fair”, “poor” or “very poor” health), using *less than good health* as cut-off point (Maas et al., 2006; Triguero-Mas et al., 2015). Natural cause mortality was defined using ICD-10

codes A00-R99. We excluded deaths registered as consequences of external causes in order to exclusively study associations operating through biological pathways of UGS exposure.

Residential Urban Green Spaces

Exposure to residential urban green spaces (UGS) was measured using one objective (surrounding greenness) and one subjective (perceived neighbourhood greenness) indicator. **Surrounding greenness** was measured with the Normalized Difference Vegetation Index (NDVI), a measure of green density based on satellite imagery applying the ratio between visible and near-infrared light bands. NDVI values range from 0 to 1, with values closer to one indicating higher green density (Weier and Herring, 2000). The calculation of the NDVI was performed over a set of atmospherically corrected satellite images from the Landsat-5 for the summer period of 2006, with a 30x30m spatial resolution. The average NDVI value for surrounding greenness was calculated using the centroids of the grid cells in which each XY coordinate of the individuals' residential address was located (Bauwelinck et al., 2021). Three buffer sizes were available: 300-m, 500-m and 1,000-m. **Perceived neighbourhood greenness** was obtained from the 2001 census, where each head of household was asked to rate the provision of green spaces in their neighbourhood ("Poorly equipped", "Normally equipped" or "Very well equipped"). We calculated the percentage of households in each statistical ward (i.e., the basic territorial unit in Belgium, comparable to neighbourhoods) who reported having very well-equipped green spaces in their neighbourhoods. In the BCR the average size of a statistical ward is 21ha, ranging from 1 to 751ha.

Three intersectionality dimensions

The intersectionality approach was operationalized by including three important dimensions of social stratification: gender, socioeconomic position (SEP) and migrant background (Bowleg, 2012; Krieger, 2001).

Individual socioeconomic position (SEP) was captured through two indicators: educational attainment and housing tenure. Educational attainment is a stable, widely available, indicator of SEP (Galobardes et al., 2006). It was classified in five groups according to the International Standard Classification of Education (UNESCO Institute for Statistics (UIS), 2012): tertiary (reference) [levels 5-8], higher secondary [levels 3-4], and lower education [levels 0-2]. Housing tenure was included as an indicator of long-term material wealth and was categorized as: owner (reference) and tenant. Individuals with missing information on one of these variables were excluded (N=68,551; 9%).

Migrant background captured the family history of migration using information from the 1991 in addition to the 2001 census, and was categorized into Belgian, other high-income country [HIC] and low- and middle-income country [LMIC] (for a detailed description on the criteria followed for classification, see Supplementary Methods S1 and Table S1).

Potential confounders

We considered age, household living arrangement, area-level SEP, and outdoor air and noise pollution as potential confounders. Age was included both as a continuous and as a categorical variable. The latter was included to account for cohort effects, and consists of the following categories: 16-24 years, 25-39 years, 40-64 years, 65-80 years. Household living arrangement was categorized into single, cohabiting with the partner and other. Area-level SEP was approximated as the percentage of unemployed over the total working population at the statistical ward level. In order to avoid extreme values, individuals living in statistical wards with less than 200 inhabitants were excluded (97 statistical wards; N=3,623, <1%).

Outdoor environment covariates consist of modelled ambient air and noise pollution estimates. These were linked to the residential address of each respondent. High resolution ambient air pollution data for the year 2005 was provided at 25x25m grids by the Belgian Interregional Environment Agency (IRCEL-CELINE) (www.irceline.be). In Belgium, concentrations of several air pollutants are continuously measured through a wide network of monitoring stations. This data is used in spatial-temporal (kriging) interpolation models and combined with a Gaussian dispersion model based on emissions from traffic and industrial sources and including meteorological data to calculate pollutant concentrations (Hooyberghs et al., 2006; Lefebvre and Vranckx, 2013). In this study, we included annual mean concentrations ($\mu\text{g}/\text{m}^3$) at the residential address of particulate matter with an aerodynamic diameter smaller than $10\mu\text{m}$ (PM_{10}) and $2.5\mu\text{m}$ ($\text{PM}_{2.5}$), nitrogen dioxide (NO_2) and black carbon (BC). BC concentrations were available for the year 2010. Data on 2016 noise pollution was provided by Brussels Environment, the official regional environment agency (<https://leefmilieu.brussels>) at fine spatial resolution (10x10 m) for road, rail, air, and multi-exposure (road/rail/air) noise. Noise levels are measured through 17 permanent measurement stations situated in strategical places of the BCR, registering the influence of a single means of transportation. Additionally, mobile sound level meters were used to validate the results. Average noise levels were calculated for four indicators: L_{day} (07h-19h), L_{evening} (19h-23h), L_{night} (23h-07h) and L_{den} (energetic combination of L_{day} , L_{evening} and L_{night} = 24 hours). For the calculation of the L_{den} global indicator, L_{evening} and L_{night} were respectively rescaled by a 5dB and a 10dB increase for the greater nuisance experienced when exposed to noise during those hours (Brussels Environment, 2018). We used combined daily average multi-exposure transportation noise levels (L_{den}) in a decibel scale (dB(A)).

Statistical analyses

We conducted all statistical analyses in Stata (version 14; StataCorp). Multilevel logistic regression models were performed to obtain odds ratios (ORs) and their 95% confidence intervals (95%CI) for poor self-perceived health. Multilevel Cox proportional hazards models, using age as the underlying time scale, were conducted to obtain hazard ratios (HRs) and their 95% CI for natural cause mortality. Observations were censored when emigration, death from external causes or end of follow-up occurred, whichever came first. In our main analyses, we included the 300-m buffer of surrounding greenness, representing the average walking distance that a Brussels resident needs to walk to go to any public green space (Van de Voorde, 2016). We presented one model for each residential UGS indicator separately. Effect estimates were expressed for increases of one interquartile range (IQR) for the two indicators of residential UGS. Our main model was constructed stepwise, including cumulatively the intersectionality dimensions and the potential confounders in successive models: M1 was adjusted by age and gender; M2 added migrant background; M3 added educational attainment, housing tenure and household living arrangement; M4 added $\text{PM}_{2.5}$ and daily average multiple source noise exposure (L_{den}); and M5 added area-level SEP.

We tested for the linearity of the exposure-response associations by comparing our main model, including the linear term of the exposure, with a model where natural splines with two degrees of freedom were specified for the UGS indicators (Figure 1). Model comparison was performed using the likelihood-ratio test (LRT). We observed a significant deviation from linearity in the models estimating the association between surrounding greenness and poor self-perceived health and between perceived neighbourhood greenness and natural cause mortality. For these two cases, we repeated the analyses for the main models categorising the continuous indicators of UGS into quintiles of exposure (Table S3).

Intersectionality was studied using a gradual approach. First, each social stratification variable (gender, educational attainment and migrant background) was introduced as a multiplicative interaction term for the association between UGS and the outcomes separately. The statistical significance of the multiplicative interaction term was tested through the improvement of model fit compared to the main effects model using a likelihood ratio test, following the methodology used in a previous study (Dadvand et al., 2014). This likelihood ratio test can be considered as a formal test of the statistical significance of the effect modification caused by socioeconomic and demographic characteristics. In addition, analyses were stratified. Then, the statistical significance of the second-grade interaction terms was estimated with the same method in order to assess intersectionality effects between gender and each of the other two social dimensions. Likewise, these combinations were then stratified. Thirdly, this process was repeated for the third-grade interaction terms, analyses being finally stratified by gender, educational attainment and migrant background simultaneously. The combination of this gradual approach and the evaluation of interaction effects before conducting stratification allowed us to explore in a parsimonious way effect modification through intersecting social dimensions. Aforementioned approach allows step by step assessment of between-group heterogeneity in the association between UGS and health (Scott and Siltanen, 2017). A similar method has been used in a previous study adopting an intersectionality lens to gender, sexual minority and Hispanic ethnic identity and their interaction with experiences of bullying and its relation with suicide attempts (LeVasseur et al., 2013).

In additional analyses, we estimated the mediation effects of each of the ambient air pollutants ($PM_{2.5}$, PM_{10} , NO_2 and BC) on associations between residential UGS indicators and poor self-perceived health and natural cause mortality. For each mediator, we fitted two fully adjusted models (i.e., including all our covariates): a model A of the association between the exposure and the outcome (including the mediator), and a linear regression model B of the association between the exposure and the mediator. Model A calculates the total effect and model B calculates the effect of the exposure on the mediator. The average causal mediation effects (also called indirect effects) and the average direct effects can be estimated from these two models. Subsequently, we can calculate the proportion of outcome reduction (poor self-perceived health or natural cause mortality) in the association with residential UGS explained by the studied mediators (Bauwelink et al., 2021; Imai et al., 2010). The linear associations between both residential UGS indicators and noise pollution levels (L_{den}) were positive, which was counterintuitive, and we therefore decided to not to conduct the mediation analyses for this variable.

We conducted sensitivity analyses to assess the robustness of our findings. First, to account for the missing covariate data, we conducted multiple imputation by chained equations, carrying out 15 multiple imputations with 10 cycles of iterations each, that generated 15 complete datasets. Second, as our main models were adjusted by $PM_{2.5}$ concentrations, all analyses were repeated using other air pollutants in the models (PM_{10} , NO_2 or BC). Third, we limited our analyses to certain population groups: (a) we excluded movers, i.e., we only included individuals who lived in the same statistical ward in 1991 and in 2001, assuming that they did not change residence 10 years prior to baseline; (b) we excluded individuals living in social housing; and (c) we excluded students, since their educational attainment or housing tenure are not likely to reflect their true socioeconomic position. Finally, we re-ran the analyses to assess potential influences on UGS exposure: (a) when using different buffer sizes (500-m and 1,000-m) for surrounding greenness; and (b) when excluding individuals with a private garden.

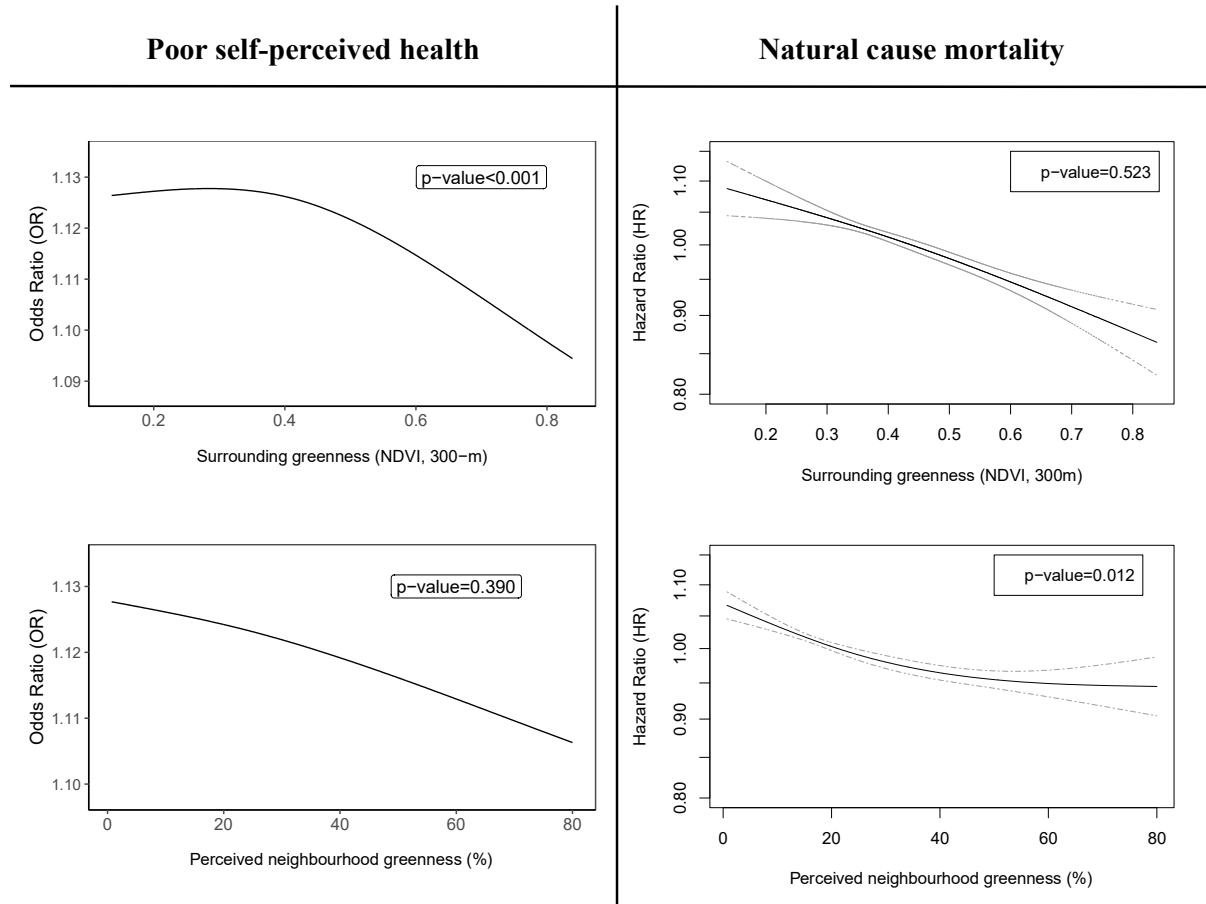


Figure 1. Exposure-response curves (natural splines with two degrees of freedom) between the UGS indicators and poor self-perceived health (odds ratio, OR) and 95% confidence interval (95%CI) and natural cause mortality (hazard ratio, HR) and 95%CI.

3. Results

The general characteristics of the total study population at baseline (year 2001) and information on mortality and emigration during follow-up (2001-2014) are presented in Table 1. In total, 571,558 individuals were included at baseline. The mean age at baseline was 44 years ($\pm$ standard deviation (SD) 17.1). More than three quarters of the population was of Belgian origin (57% of the total population) and the group of residents originating from LMIC was larger (25%) than the group originating from other HIC (19%). During the follow-up period (2001-2014), about 9% (N=27,629) of men and 8% (N=22,824) of women emigrated from the BCR. Deaths from natural causes during follow-up were slightly higher among men than among women (14% vs 12%), while in 2001, more women reported having poor self-perceived health (29%) than men (25%).

	Total	Women	Men
	N = 571,558	N = 272,345	N = 299,213
Age at baseline, mean $\pm$ SD	44 $\pm$ 17.1	44 $\pm$ 17.4	43 $\pm$ 16.7
Poor self-perceived health, N (%)	154,166 (27.0)	86,607 (28.9)	67,559 (24.8)
Deaths due to natural causes (2001-2014), N (%)	72,355 (12.7)	34,715 (11.6)	37,640 (13.8)
Emigrations (2001-2014), N (%)	50,453 (8.8)	22,824 (8.4)	27,629 (9.2)
Migrant background, N (%)			
Belgian	323,361 (56.6)	173,528 (58.0)	149,833 (55.0)
Other HIC	108,077 (18.9)	56,292 (18.8)	51,785 (19.0)
LMIC	140,128 (24.5)	69,397 (23.2)	70,731 (26.0)
Educational attainment, N (%)			
Tertiary Education	191,286 (33.5)	97,805 (32.7)	93,481 (34.3)
Higher Secondary Education	146,343 (25.6)	77,002 (25.7)	69,341 (25.5)
Lower Education	233,937 (40.9)	124,410 (41.6)	109,527 (40.2)
Housing tenure, N (%)			
Owner	291,276 (51.0)	153,031 (51.1)	138,245 (50.8)
Tenant	280,290 (49.0)	146,186 (48.9)	134,104 (49.2)
Household living arrangement, N (%)			
Single	183,359 (32.1)	108,358 (36.2)	75,001 (27.5)
Cohabiting w/Partner	284,568 (49.8)	142,223 (47.5)	142,345 (52.3)
Other	103,639 (18.1)	48,636 (16.3)	55,003 (20.2)
Area-level SEP (% of unemployment), median (IQR)	17.5 (13.7)	17.3 (12.1)	17.8 (14.7)
Indicators of residential urban green spaces, median (IQR)			
Surrounding greenness (NDVI within 300m) (2006)	0.4 (0.2)	0.4 (0.2)	0.4 (0.2)
Perceived neighbourhood greenness (% of households reporting very well-equipped provision of green spaces in the neighbourhood)	22.8 (28.7)	23.7 (28.4)	21.95 (28.32)
PM_{2.5} ($\mu\text{g}/\text{m}^3$) (2005), mean $\pm$ SD	19.3 $\pm$ 0.9	19.3 $\pm$ 0.8	19.3 $\pm$ 0.9
Combined daily average noise levels (L_{den}) from multiple transportation sources (dB (A)) (2016), median (IQR)	49.9 (5.8)	49.9 (5.9)	49.9 (5.7)

Table 1. Baseline characteristics of the study population aged between 16 and 80, mortality and migration during follow-up (2001-2014) and residential living environment characteristics. Brussels Capital Region.

The environmental indicators included in this study were strongly to moderately correlated with each other (Figure S1). Surrounding greenness showed strong correlations with perceived neighbourhood greenness ($r=0.80$), low to moderate correlations with air pollutant concentrations and very weak with daily average noise levels. Moderate negative associations were observed between surrounding greenness and the area-level SEP indicator ($r=-0.62$).

The associations of residential UGS with the health outcomes for the total population, with stepwise cumulative adjustment for potential confounders are shown in Figure 2 and fully reported in Table S2. Poor self-perceived health and natural cause mortality were inversely associated with both indicators

of residential UGS. After control for individual- and area-level socioeconomic characteristics the associations attenuated considerably (M3 and M5). Surrounding and perceived neighbourhood greenness showed similar inverse associations for poor self-perceived health and natural cause mortality in the fully adjusted models [e.g., for surrounding greenness: odds ratio (OR) 0.92 (95% confidence intervals (CI): 0.90, 0.94); hazard ratio (HR) 0.94 (95%CI: 0.92, 0.95); respectively]. On the other hand, the inclusion of the variables accounting for environmental hazards (PM_{2.5} concentrations and daily average noise levels) barely affected the associations (M4).

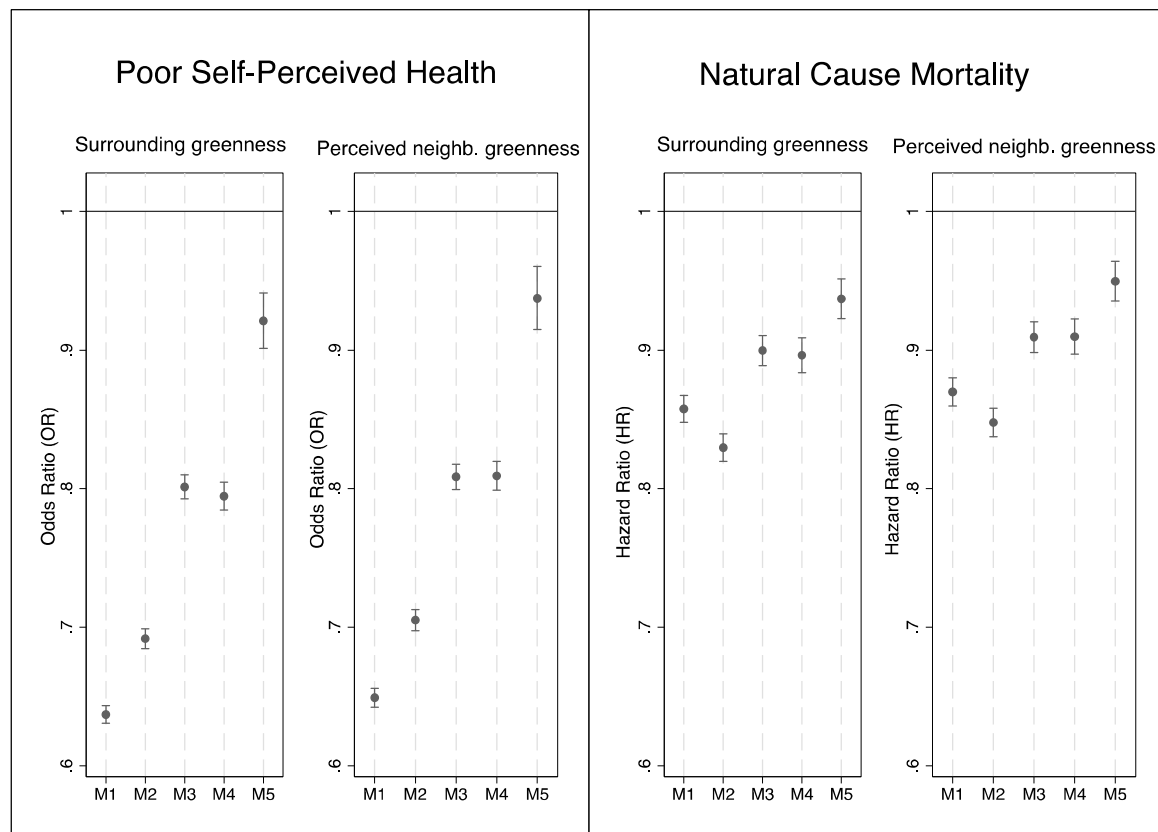


Figure 2. Stepwise adjustment of the associations and 95% confidence intervals (95%CI) between an IQR increment in residential urban green spaces and poor self-perceived health (Odds Ratio, OR) and natural cause mortality (Hazard Ratio, HR). M1 was adjusted by age and gender; M2 added migrant background; M3 added educational attainment, housing tenure and household living arrangement; M4 added PM_{2.5} and L_{den}; and M5 added area-level SEP. Brussels Capital Region, 2001-2014. Note: We used multilevel logistic regression models for the association with poor self-perceived health in 2001, and Cox proportional hazard models using age as the underlying time scale for the association with natural cause mortality during follow-up (2001-2014).

Supplementary analyses using a categorisation of the exposure variables into quintiles to check the linearity of the exposure-response association were conducted (Table S3). We did not find major deviations from linearity, and hence we decided to continue the analyses with the continuous term. Table 2 shows the fully adjusted (M5) associations between self-perceived health and natural cause mortality and the two residential UGS indicators, stratified by gender, educational attainment, and

migrant background subsequently. These associations were also modelled including interaction terms between each UGS indicator and each of the three social dimensions, for each one of the outcomes. A likelihood ratio test was conducted comparing the models including the interaction with the fully adjusted model M5 (p-values in italics). All first-grade interaction terms were significant for poor self-perceived health, while for natural cause mortality only migrant background was a statistically significant effect modifier. Results were overall similar for both surrounding greenness and perceived neighbourhood greenness. By gender, slightly stronger inverse associations were observed for men compared to women regarding self-perceived health and for women compared to men regarding natural cause mortality. When stratifying by educational attainment, we generally observed the strongest inverse associations among the group with lower education [e.g., for surrounding greenness and mortality: HR 0.94 (95%CI: 0.92, 0.95)]. Nevertheless, for surrounding greenness, the associations were also strong among the group with tertiary education. Regarding migrant background, we observed inverse significant associations with both health outcomes in every stratum. Among residents originating from LMIC, the association between perceived neighbourhood greenness and natural cause mortality was not significant.

	Poor self-perceived health †		Natural cause mortality ‡	
	Surrounding greenness	Perceived neighbourhood greenness	Surrounding greenness	Perceived neighbourhood greenness
	OR (95%CI)	OR (95%CI)	HR (95%CI)	HR (95%CI)
Gender				
Women	0.93 (0.91, 0.96)*	0.95 (0.92, 0.98)*	0.93 (0.91, 0.95)*	0.94 (0.92, 0.96)*
Men	0.92 (0.90, 0.95)*	0.93 (0.90, 0.95)*	0.94 (0.92, 0.97)*	0.96 (0.94, 0.98)*
<i>p-value for interaction ^a</i>	<i><0.001</i>	<i><0.001</i>	<i>0.831</i>	<i>0.650</i>
Educational attainment				
Tertiary Education	0.93 (0.90, 0.97)*	0.97 (0.94, 1.01)	0.92 (0.89, 0.96)*	0.95 (0.91, 0.98)*
Higher Secondary Education	0.95 (0.92, 0.98)*	0.96 (0.93, 0.99)*	0.96 (0.92, 0.99)*	0.97 (0.94, 1.01)
Lower Education	0.93 (0.90, 0.95)*	0.92 (0.89, 0.94)*	0.94 (0.92, 0.95)*	0.94 (0.92, 0.96)*
<i>p-value for interaction ^a</i>	<i><0.001</i>	<i><0.001</i>	<i>0.720</i>	<i>0.914</i>
Migrant background				
Belgian	0.94 (0.92, 0.96)*	0.95 (0.93, 0.97)*	0.94 (0.92, 0.95)*	0.95 (0.93, 0.96)*
Other HIC	0.90 (0.87, 0.94)*	0.92 (0.88, 0.96)*	0.91 (0.87, 0.95)*	0.94 (0.90, 0.99)*
LMIC	0.93 (0.89, 0.96)*	0.93 (0.89, 0.98)*	0.95 (0.90, 1.00)*	0.97 (0.92, 1.03)
<i>p-value for interaction ^a</i>	<i><0.001</i>	<i><0.001</i>	<i><0.001</i>	<i><0.001</i>

Note: OR, Odds Ratio; HR, Hazard Ratio; 95%CI, 95% Confidence Intervals. † Multilevel logistic regression models for 2001. ‡ Cox proportional hazards models using age as the underlying time scale, follow-up period 01 October 2001 - 31 December 2014. * p-value < 0.05. Models adjusted by age, gender, migrant background, educational attainment, housing tenure, household living arrangement, PM_{2.5}, L_{den} and area-level SEP. Surrounding greenness IQR: 0.2, Perceived neighbourhood greenness IQR: 28.7.

^a Reported p-value derived from the likelihood ratio test comparing the goodness of fit of the main model with the model including the interaction term.

Table 2. Adjusted associations and 95% confidence intervals between IQR increments of residential greenness and perceived neighbourhood greenness and poor self-perceived health and natural cause mortality, stratified by gender, educational attainment and migrant background. Brussels Capital Region, 2001-2014.

The results of the second-grade intersections (gender with educational attainment and gender with migrant background) for the exposure to surrounding greenness are presented in Figure 3 and fully reported in Tables S3-S4. The results of the same models with perceived neighbourhood greenness did almost not differ and are shown in Tables S3-S4. Each of the models including the second-grade interaction terms fitted the data better compared to the first-order interaction models they are nested in. When stratifying by gender and educational attainment, for poor self-perceived health, we observed that, among women, the inverse associations showed a gradient across education strata: the lower the educational attainment, the stronger the associations. Associations were only significant among low-educated women [for surrounding greenness: OR 0.92 (95%CI: 0.89, 0.95)]. Among men, the strongest inverse associations were observed in the tertiary educated, but significant inverse associations were also found in the lower education strata. For natural cause mortality, a similar pattern was observed; however, among women, there was an additional significant protective effect of surrounding greenness in the tertiary educated. Results stratifying by gender and migrant background revealed, for poor self-perceived, that the strongest beneficial associations among women were found in residents originating from other HIC and from LMIC. Among men, significant inverse associations were found in residents originating from Belgium and from other HIC, but not from LMIC. For natural cause mortality, no significant inverse associations were found in residents of LMIC-origin neither in men nor in women. Among women, the strongest beneficial associations were found in residents originating from HIC [HR 0.87 (95%CI: 0.82, 0.94)], whereas among men these were found in residents of Belgian origin.

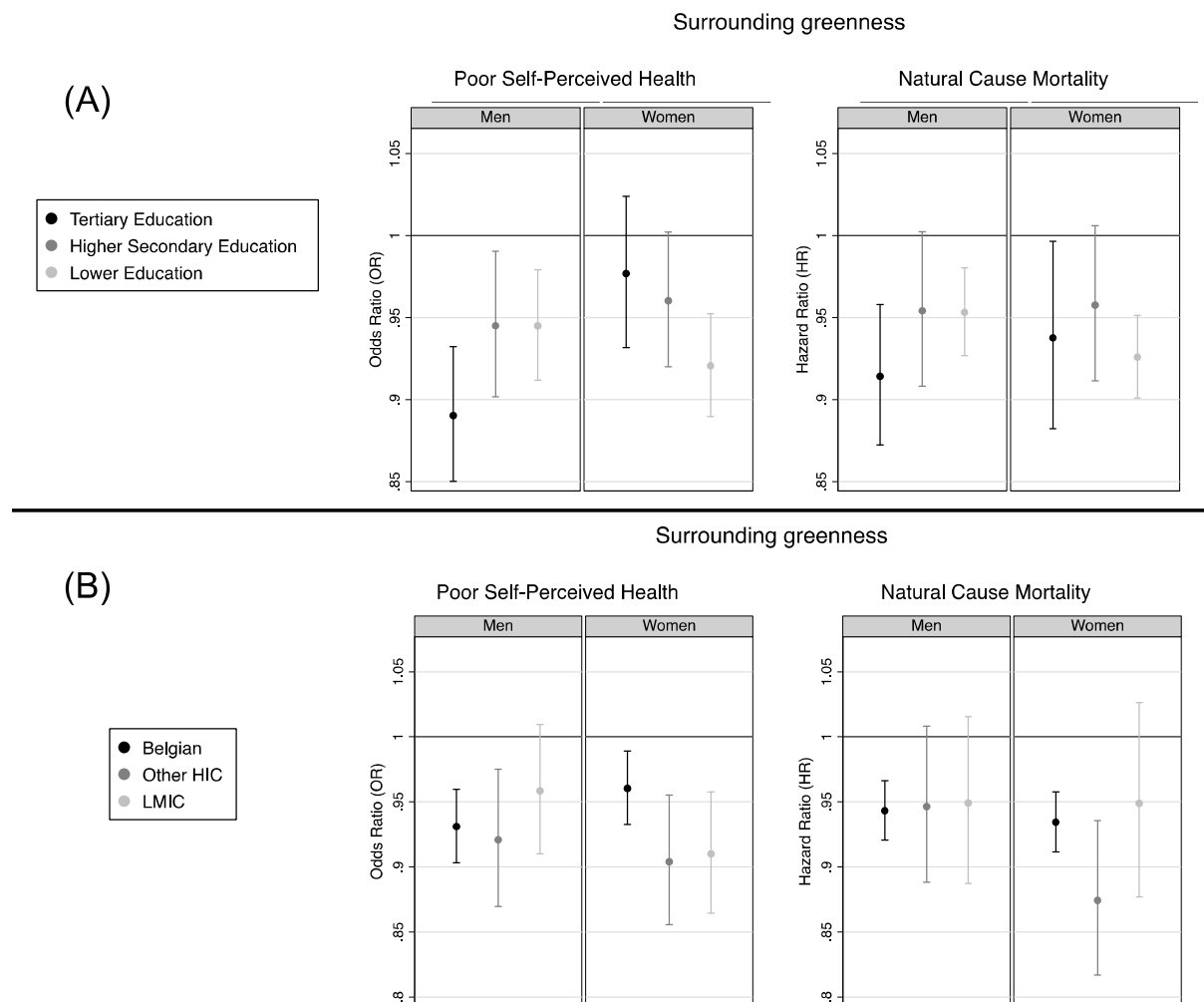


Figure 3. Adjusted associations and 95%CI between IQR increments of residential surrounding greenness and poor self-perceived health (OR) and natural cause mortality (HR), stratified by (A) gender and educational attainment, (B) gender and migrant background. Brussels Capital Region, 2001-2014. Note: We used multilevel logistic regression models for the association with poor self-perceived health in 2001, and Cox proportional hazard models using age as the underlying time scale for the association with natural cause mortality during follow-up (2001-2014). Models were adjusted for age, migrant background, educational attainment, housing tenure, household living arrangement, $PM_{2.5}$ and L_{den} , and area-level SEP.

Including the third-grade interaction terms improved the model fit when compared to the second-grade interaction models. The associations with surrounding greenness and perceived neighbourhood greenness stratified by gender, educational attainment and migrant background are displayed for poor self-perceived health in Table 3 and for natural cause mortality in Table 4. The results for both health outcomes were similar using both UGS indicators. For poor self-perceived health and among women, we found significant inverse associations only in the lower educated, regardless of their migrant background [e.g., for surrounding greenness and LMIC-origin: OR 0.92 (95%CI: 0.86, 0.98)]. Among men, the strongest beneficial associations were found in the tertiary educated in every migrant background; however, these associations were only significant in men originating from Belgium and

from other HIC. Among men of Belgian origin, significant associations were also found in the lower educated. For natural cause mortality, the results for residents of Belgian origin were similar to those shown in Figure 2: among women, the strongest associations were found in the lower educated, although with surrounding greenness there was also a strong protective effect in the tertiary educated; among men, we observed the strongest inverse associations among the tertiary educated. A strong inverse association was found in higher secondary educated women originating from other HIC [for surrounding greenness: HR 0.82 (95%CI: 0.70, 0.96)]. The results for mortality in residents of LMIC-origin were not significant.

Poor self-perceived health						
Migrant background						
Belgian			Other HIC		LMIC	
	N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
Surrounding greenness						
Women						
Educational attainment						
Tertiary Education	62,493	0.97 (0.92, 1.03)	21,610	0.99 (0.89, 1.11)	13,698	0.94 (0.85, 1.05)
Higher Secondary Education	44,069	0.99 (0.94, 1.04)	13,496	0.92 (0.83, 1.02)	19,437	0.92 (0.84, 1.00)
Lower Education	66,965	0.94 (0.90, 0.98)*	21,184	0.87 (0.81, 0.93)*	36,261	0.92 (0.86, 0.98)*
Men						
Educational attainment						
Tertiary Education	57,496	0.90 (0.85, 0.95)*	20,018	0.85 (0.76, 0.95)*	15,965	0.92 (0.82, 1.03)
Higher Secondary Education	37,935	0.93 (0.87, 0.98)*	11,680	0.97 (0.86, 1.10)	19,726	1.00 (0.91, 1.10)
Lower Education	54,401	0.95 (0.91, 0.99)*	20,084	0.95 (0.88, 1.02)	35,040	0.96 (0.90, 1.03)

Table 3. Adjusted associations and 95%CI between IQR increments of residential surrounding greenness and perceived neighbourhood greenness and poor self-perceived health (OR), stratified by gender, educational attainment and migrant background. Brussels Capital Region, 2001.

Poor self-perceived health						
Migrant background						
	Belgian		Other HIC		LMIC	
	N	OR (95%CI)	N	OR (95%CI)	N	OR (95%CI)
Perceived neighbourhood greenness						
Women						
Educational attainment						
Tertiary Education	62,493	1.01 (0.96, 1.07)	21,610	1.04 (0.93, 1.16)	13,698	0.94 (0.84, 1.05)
Higher Secondary Education	44,069	0.99 (0.94, 1.04)	13,496	0.95 (0.85, 1.05)	19,437	0.97 (0.88, 1.07)
Lower Education	66,965	0.95 (0.91, 0.99)*	21,184	0.85 (0.79, 0.91)*	36,261	0.91 (0.85, 0.98)*
Men						
Educational attainment						
Tertiary Education	57,496	0.93 (0.89, 0.98)*	20,018	0.89 (0.80, 1.00)	15,965	0.95 (0.85, 1.07)
Higher Secondary Education	37,935	0.95 (0.90, 1.00)*	11,680	0.95 (0.84, 1.08)	19,726	1.00 (0.90, 1.12)
Lower Education	54,401	0.93 (0.89, 0.97)*	20,084	0.96 (0.89, 1.04)	35,040	0.97 (0.90, 1.05)
Note: OR, Odds Ratio; 95%CI, 95% Confidence Intervals. * p-value < 0.05. Multilevel logistic regression models for 2001. Models adjusted by age, housing tenure, household living arrangement, PM _{2.5} , L _{den} and area-level SEP.						

Table 3. (Continued).

Natural cause mortality						
Belgian		Other HIC		LMIC		
	N	HR (95%CI)	N	HR (95%CI)	N	HR (95%CI)
Surrounding greenness						
Women						
Educational attainment						
Tertiary Education	62,493	0.93 (0.87, 0.99)*	21,610	0.91 (0.75, 1.11)	13,698	1.13 (0.89, 1.43)
Higher Secondary Education	44,069	0.97 (0.92, 1.02)	13,496	0.82 (0.70, 0.96)*	19,437	1.01 (0.83, 1.23)
Lower Education	66,965	0.93 (0.90, 0.95)*	21,184	0.88 (0.81, 0.96)*	36,261	0.91 (0.83, 1.00)
Men						
Educational attainment						
Tertiary Education	57,496	0.91 (0.87, 0.96)*	20,018	0.94 (0.81, 1.10)	15,965	0.92 (0.77, 1.08)
Higher Secondary Education	37,935	0.95 (0.90, 1.01)	11,680	0.94 (0.80, 1.12)	19,726	0.95 (0.81, 1.13)
Lower Education	54,401	0.95 (0.92, 0.98)*	20,084	0.95 (0.88, 1.03)	35,040	0.95 (0.88, 1.03)

Table 4. Adjusted associations and 95%CI between IQR increments of residential surrounding greenness and perceived neighbourhood greenness and natural cause mortality (HR), stratified by gender, educational attainment and migrant background. Brussels Capital Region, 2001-2014.

Natural cause mortality						
Migrant background						
	Belgian		Other HIC		LMIC	
	N	HR (95%CI)	N	HR (95%CI)	N	HR (95%CI)
Perceived neighbourhood greenness						
Women						
Educational attainment						
Tertiary Education	62,493	0.96 (0.90, 1.02)	21,610	1.00 (0.82, 1.21)	13,698	1.02 (0.79, 1.30)
Higher Secondary Education	44,069	0.97 (0.92, 1.02)	13,496	0.83 (0.71, 0.97)*	19,437	1.03 (0.83, 1.26)
Lower Education	66,965	0.93 (0.91, 0.96)*	21,184	0.94 (0.86, 1.02)	36,261	0.93 (0.84, 1.03)
Men						
Educational attainment						
Tertiary Education	57,496	0.95 (0.90, 1.00)*	20,018	0.87 (0.74, 1.02)	15,965	0.99 (0.83, 1.17)
Higher Secondary Education	37,935	0.97 (0.93, 1.03)	11,680	1.07 (0.91, 1.25)	19,726	1.08 (0.90, 1.30)
Lower Education	54,401	0.95 (0.92, 0.98)*	20,084	0.99 (0.91, 1.08)	35,040	0.96 (0.87, 1.05)
Note: HR, Hazard Ratio; 95%CI, 95% Confidence Intervals. * p-value < 0.05. Cox proportional hazards models using age as the underlying time scale, follow-up period 01 October 2001 - 31 December 2014. Models adjusted by age, housing tenure, household living arrangement, PM _{2.5} , L _{den} and area-level SEP.						

Table 4. (Continued).

The results of the mediation analyses can be found in Table S6. According to these, between 12-16% of the associations between both residential UGS indicators and poor self-perceived health are potentially mediated by PM₁₀. This was however not observed with natural cause mortality nor with any other pollutants.

In sensitivity analyses, we used multiple imputation, we adjusted our models for different pollutants (i.e., PM₁₀, NO₂ or BC instead of PM_{2.5}), excluded individuals who moved neighbourhoods between 1991 and 2001 (10 years prior to baseline), students and residents living in social housing and those without a private garden, and we repeated our analyses for larger buffers for surrounding greenness (i.e., 500-m and 1,000-m) and individuals without a garden. Overall, our results were robust to the sensitivity analyses conducted (Table S7), although some differences were observed when using different buffer sizes and excluding individuals with a private garden (Tables S8-S11). When using the 500-m and 1,000-m buffer for surrounding greenness, inverse significant associations for natural cause mortality were also found among low-educated women of LMIC-origin. When excluding residents without a garden, the associations between poor self-perceived health and surrounding and perceived neighbourhood greenness were no longer significant, except for low-educated women originating from other HIC. Additionally, with perceived neighbourhood greenness, we observed an inverse association also among low-educated men originating from Belgium. For natural cause mortality, beneficial associations were observed with the two residential UGS indicators among low-educated men of LMIC-origin.

4. Discussion

This study investigated the effect modification of several socioeconomic and demographic dimensions in the relationship between residential UGS and health by applying an intersectional approach. In line with previous studies, we found an inverse association of UGS with poor self-perceived health (Agyemang et al., 2007; Dadvand et al., 2016; de Vries et al., 2003; Klompaker et al., 2019; Maas et al., 2006; Orban et al., 2017; Triguero-Mas et al., 2015; Van Dillen et al., 2012) and natural cause mortality (Bauwelink et al., 2021; Crouse et al., 2017; James et al., 2016; Orioli et al., 2019; Vienneau et al., 2017; Villeneuve et al., 2012). Our models were adjusted by several sociodemographic and socioeconomic variables, at both the individual and the area-level. However, we cannot dismiss residual confounding for other variables that were not available in our dataset. For instance, lifestyle factors, such as BMI or smoking status could have also affected our findings, although these might be highly determined by the sociodemographic and socioeconomic characteristics considered and, moreover, previous studies adjusting by these variables showed similar results as ours (Crouse et al., 2017; Klompaker et al., 2019). We also lacked information on potential mediators of the association between green spaces and health, such as physical activity, or other contextual elements like social cohesion (Dadvand et al., 2016). Notwithstanding these potential limitations, and bearing in mind important methodological, contextual and population variations across studies, our results were fairly comparable in strength to those of the existing literature on UGS and poor self-perceived health (Klompaker et al., 2019; Triguero-Mas et al., 2015) and natural cause mortality (Crouse et al., 2017; Vienneau et al., 2017). Although the health-related effects of environmental exposures are more modest than the well-known effects of individual risk factors (such as smoking or physical activity), their importance is crucial since they affect entire populations and are easily modifiable.

The results of the intersectional analyses suggest an interaction between residential UGS, gender, educational attainment and migrant background in the association with the outcomes studied. For poor self-perceived health, among women, we observed that the strongest beneficial associations

were found in those with lower education, for every migrant background. Conversely, among men, they were found in the tertiary educated, although they were only significant in men originating from Belgium and other HIC. In men of Belgian origin, we also found protective associations in the lower educated. For natural cause mortality, our findings suggest an additional beneficial effect for tertiary educated women of Belgian origin when exposed to higher levels of surrounding greenness, and of residential urban green spaces for women originating from other HIC with higher secondary education. No significant associations with natural cause mortality were found in LMIC-origin residents.

Intersection analyses clearly showed an interaction between UGS, gender and educational attainment in the associations with both (health) outcomes. As far as we know, only one study focusing on the relationship between park availability and BMI in children has assessed the effect modification by gender and an indicator of socioeconomic position simultaneously (Hughey et al., 2017). Contrary to our findings, higher availability of parks near the residence was associated with lower BMI among the low SEP group of boys, while among girls this was found in the high SEP group. Our findings for women are however in agreement with the existing literature using a similar methodology and focusing on the relationship between UGS exposure and birth outcomes [therefore including only (pregnant) women]. These studies have consistently found stronger beneficial effects of green spaces on several outcomes in the low-educated (Dadvand et al., 2014, 2012a, 2012b; McEachan et al., 2016). In a recent review, (Nieuwenhuijsen et al., 2017) highlighted that low SEP groups and women might benefit more from green spaces than other social groups. Interestingly, in our study, this pattern was consistent in every migrant background, which could indicate that, in Brussels, the beneficial effects of green spaces on health among women with lower education do not depend on cultural differences in uses or attitudes towards UGS. Women in a low socioeconomic position might rely to a greater extent on local resources and nearby social contacts, being more susceptible to contextual factors (Stafford et al., 2005). In parallel, they usually spend more time in and around the house, resulting in a higher exposition to residential green spaces (de Vries et al., 2003; Maas et al., 2009).

We found a significant decreased risk of natural cause mortality with surrounding greenness – but not with perceived neighbourhood greenness – among women with tertiary education originating from Belgium. This association was no longer significant when excluding residents with a private garden. Because surrounding greenness is an unspecific indicator of green, it is hard to discern which type of green is explaining the observed beneficial associations with health. Comparatively, perceived neighbourhood greenness might also capture other characteristics of the residential environment, such as walkability or perceived safety, which may play a role in the relationship with health (Sugiyama et al., 2008). Using subjective indicators of green spaces in addition to the objective ones might help to better understand which groups benefit the most from living near green spaces and map out health inequalities.

An opposite trend was observed for men, although we did find beneficial associations on health in the lower educated of Belgian origin. A greater beneficial effect of green spaces in the tertiary educated men might be related to a more active use of them, since education is a predictor of physical activity (Gidlow et al., 2006) and men are more likely to exercise in open public green spaces (Cohen et al., 2007). More research is needed to assess the intersection between residential UGS, gender and educational attainment in the relationship with health outcomes.

We found significant interactions between residential UGS indicators and migrant background for both health outcomes, but the differences between the groups were very subtle. Among men originating from LMIC, we observed no significant beneficial associations on health of living near

greener spaces. To our knowledge, only three studies conducted in the UK have assessed the effect modification by ethnicity in the relationship between green spaces and different health indicators. Despite all being based on the Born in Bradford cohort, they show mixed results, and only one focused on an adult population, similar to ours (Dadvand et al., 2014; McEachan et al., 2018, 2016). One study observed positive associations between surrounding greenness and birth weight among singleton live-births of White British mothers, but not among those of Pakistani women (Dadvand et al., 2014). Another study found improved mental health among 4-year-old South Asian children, but not among White children (McEachan et al., 2018). In contrast, when studying green spaces and depressive symptoms among pregnant women, no apparent effect modification by ethnicity was found (McEachan et al., 2016). Comparing these results might be difficult however, as the cultural background of the studied groups and the assessed health outcomes are very different.

From the residents originating from LMIC in our study, almost 50% came from Morocco and 15% from Turkey. In Belgium, men originating from these countries arrived as guest labourers in the post-war period and in the 1970s, and women followed afterwards for family reunification (Bauwelinck et al., 2016). These groups settled in working-class neighbourhoods located in the inner city, characterized by inexpensive low housing quality, poor infrastructure and demographic pressure (Van Hamme et al., 2016). Within these areas, opportunities of exposure to green spaces are relatively limited. In our study, median levels of very good perceived neighbourhood greenness were 28% (IQR: 14–42) among Belgians, 22% (IQR: 9–37) among residents from other HIC and 9% (IQR: 5–24) among residents from LMIC. The differences between women and men in the associations between green spaces and health in this group are therefore intriguing. Because increasing the buffer size strengthened the inverse associations found between residential UGS and both health outcomes in women originating from LMIC, we venture that men from the same migrant background might have less opportunities or motivations to travel to greener areas.

We only found a relatively small mediation effect with PM_{10} on UGS estimates in relation to poor self-perceived health, which is similar to findings of most prior studies (Bauwelinck et al., 2021; Klompmaaker et al., 2019; Vienneau et al., 2017). We furthermore observed negative proportions of mediation effects for both BC and noise pollution. We suspect inconsistent mediation as signs between the direct and indirect effects were opposite (*results not shown*). Consequently, we considered interpretation of these negative mediation effects invalid. Two other comparable studies did identify noise pollution as a mediator in the relationship between green spaces and mortality (Orioli et al., 2019; Vienneau et al., 2017).

Our research can be framed within what (Bauer and Scheim, 2019) have called “descriptive intersectionality”, which is the focus on outcome heterogeneity across social strata. In depth explanatory analysis of the described patterns was unfortunately beyond the scope of our study. Our approach was intended as a heuristic analysis, since it allows to test independently and stepwise different dimensions in the model (Scott and Siltanen, 2017), and has furthermore been used in previous studies on intersectionality and health inequalities research (LeVasseur et al., 2013). Descriptive intersectionality in quantitative research has so far aimed at evaluating the interactions between different social dimensions and/or to perform a between-group comparison of average risks through the clustering of individuals into combined social categories (McCall, 2005; Wemrell et al., 2017). As previously mentioned, this method has been criticised for not taking into account the fluidity of different social identities, assuming immovable categories and therefore overlooking their potential heterogeneity. Additionally, the inter-categorical approach could entail the dangerous collateral effect of stigmatising and stereotyping the operationalised groups, contributing to perpetuate social

inequalities (Bauer, 2014). In order to overcome these limitations and to study within-group heterogeneity and/or the overlapping between strata, different methods have been suggested, such as analysing the discriminatory accuracy of the operationalised categories (Merlo et al., 2017) or using interacting social dimensions in multilevel analyses (Evans et al., 2018).

Potential limitations of our study are mainly related to the use of administrative data. First, as previously mentioned, we were unable to control for lifestyle factors, such as smoking status, which might have biased our results. However, studies adjusting for these variables have reported similar findings (Crouse et al., 2017; Klompaker et al., 2019). Second, we did not have time-varying variables at our disposal; factors such as housing tenure or household living arrangement might have changed with respect to the baseline during the follow-up. Third, exposure to green spaces was only assessed based on the residential address at baseline. However, we were able to select a subsample of people living in the same statistical ward 10 years prior to the baseline, for which we found robust results, therefore proving evidence of beneficial effects of long-term exposure to urban green spaces. Fourth, we selected environmental indicators for which the year of measurement was as close as possible to the middle of the follow-up period. However, the year of measurement might not be a considerable issue as it is unlikely that the spatial distribution of environmental characteristics has notably changed during follow-up (Van de Voorde et al., 2010). Fifth, although we could assess perceived neighbourhood greenness, objective indicators regarding quality were unavailable; neither information on contact with green spaces (e.g., frequency or duration) was available. Sixth, we adjusted our analyses for the percentage of unemployment in the statistical ward as a surrogate for area-level socioeconomic position. Unfortunately, other contextual indicators such as social cohesion, which may potentially mediate associations between UGS and health, were not available (de Vries et al., 2013; Nieuwenhuijsen et al., 2017). Other built environment variables, like population density, were not considered because of potential collinearity with the environmental indicators. Seventh, we used a subjective indicator of health status; however, self-perceived health is considered a reliable independent predictor of mortality and health service utilization and has been recommended to perform comparisons of health status in different populations (Jylhä, 2009).

To our knowledge, this is the first study on health-related outcomes of green spaces investigating socioeconomic and demographic inequalities applying an intersectionality approach. Our study is based on a large administrative dataset covering the entire BCR population and including a wide set of relevant indicators, i.e., socioeconomic and demographic indicators, subjective information on self-perceived health, linked to information on natural cause mortality for a 13-year follow-up. Moreover, exposure to residential UGS was assessed through objective indicators derived from high-resolution data sources, supplemented with subjective indicators obtained from census data. Additionally, high resolution information on environmental hazards, such as air and noise pollution, was available at the residential level. The application of an intersectionality approach was possible thanks to the large size of the study population, which allowed for the use of different stratification levels without losing statistical power, and the follow-up long enough to detect differences. Furthermore, using the Brussels Capital Region as study setting enabled us to investigate a population with very diverse migrant backgrounds, both from high and low and middle-income countries, and socioeconomic status.

5. Conclusions

We observed that, in Brussels, living in areas with higher residential surrounding greenness and better perception of neighbourhood greenness is inversely associated with poor self-perceived health at

baseline and death from a natural cause over a 13-year follow-up period. We found a consistent pattern showing a greater protective effect among low-educated individuals, that is especially strong among women, regardless their migrant background. We observed no statistically significant associations in men originating from LMIC countries. In order to better understand the underlying mechanisms of these associations, future research should focus on the quality of and contact with green spaces. Our research shows the importance of simultaneously taking into account several social dimensions (gender, educational attainment, and migrant background) in order to better understand social inequalities underlying the health-related benefits of green spaces. Therefore, urban planners and policy makers should take into account the distribution of different social strata in the population in order to maximize potential beneficial effects of greening strategies in cities. Besides, increasing greening infrastructure in cities has the potential to act as a driver of gentrification, which could deteriorate the health status of the most vulnerable urban dwellers and counteract the beneficial effects on health of green spaces (Cole et al., 2019); therefore, these initiatives need to be carefully assessed and be accompanied by housing and social policies aiming at combatting this undesirable phenomenon.

References

- Agyemang, C., van Hooijdonk, C., Wendel-Vos, W., Lindeman, E., Stronks, K., Droomers, M., 2007. The association of neighbourhood psychosocial stressors and self-rated health in Amsterdam, The Netherlands. *J. Epidemiol. Community Heal.* 61, 1042–1049. <https://doi.org/10.1136/jech.2006.052548>
- Astell-Burt, T., Feng, X., Kolt, G.S., 2014a. Greener neighborhoods, slimmer people ? Evidence from 246 920 Australians. *Int. J. Obes.* 38, 156–159. <https://doi.org/10.1038/ijo.2013.64>
- Astell-Burt, T., Mitchell, R., Hartig, T., 2014b. The association between green space and mental health varies across the lifecourse . A longitudinal study. *J. Epidemiol. Community Health* 68, 578–583. <https://doi.org/10.1136/jech-2013-203767>
- Bates, L.M., Hankivsky, O., Springer, K.W., 2009. Gender and health inequities : A comment on the Final Report of the WHO Commission on the Social Determinants of Health. *Soc. Sci. Med.* 69, 1002–1004. <https://doi.org/10.1016/j.socscimed.2009.07.021>
- Bauer, G.R., 2014. Incorporating intersectionality theory into population health research methodology: Challenges and the potential to advance health equity. *Soc. Sci. Med.* 110, 10–17. <https://doi.org/10.1016/j.socscimed.2014.03.022>
- Bauer, G.R., Scheim, A.I., 2019. Methods for analytic intercategory intersectionality in quantitative research: Discrimination as a mediator of health inequalities. *Soc. Sci. Med.* 226, 236–245. <https://doi.org/10.1016/j.socscimed.2018.12.015>
- Bauwelinck, M., Casas, L., Nawrot, T.S., Nemery, B., Trabelsi, S., Thomas, I., Aerts, R., Lefebvre, W., Vanpoucke, C., Van Nieuwenhuyse, A., Deboosere, P., Vandenheede, H., 2021. Residing in urban areas with higher green space is associated with lower mortality risk: A census-based cohort study with ten years of follow-up. *Environ. Int.* 148, 106365. <https://doi.org/10.1016/j.envint.2020.106365>
- Bauwelinck, M., Deboosere, P., Willaert, D., Vandenheede, H., 2016. Suicide mortality in Belgium at the beginning of the 21st century: differences according to migrant background. *Eur. J. Public Health* 27, 111–116. <https://doi.org/10.1093/eurpub/ckw159>
- BISA (Brussels Institute of Statistics and Analysis), 2017. Mini-Bru 2017: The Brussels Capital Region in figures. Brussels, Belgium: BISA.
- Bowleg, L., 2012. The Problem With the Phrase Women and Minorities : Intersectionality — an Important Theoretical Framework for Public Health. *Am. J. Public Health* 102, 1267–1273. <https://doi.org/10.2105/AJPH.2012.300750>
- Brussels Environment, 2018. Quiet.Brussels: Plan de prévention et de lutte contre le bruit et les vibrations en milieu urbain (In English: Quiet.Brussels: Urban Noise and Vibration Prevention and Control Plan). Brussels, Belgium: Brussels Environment.
- Brussels Environment, 2012. Rapport Sur l'état de la Nature en Région de Bruxelles Capitale (In English: Report on the State of Nature in the Brussels Capital Region). Brussels, Belgium: Brussels Environment.
- Cohen, D.A., McKenzie, T.L., Sehgal, A., Williamson, S., Golinelli, D., Lurie, N., 2007. Contribution of Public Parks to Physical Activity. *Am. J. Public Health* 97, 509–514. <https://doi.org/10.2105/AJPH.2005.072447>
- Cole, H.V.S., Triguero-Mas, M., Connolly, J.J.T., Anguelovski, I., 2019. Determining the health benefits of green space : Does gentrification matter ? *Health Place* 57, 1–11. <https://doi.org/10.1016/j.healthplace.2019.02.001>
- Crenshaw, K., 1989. Demarginalizing the Intersection of Race and Sex: A Black Feminist Critique of

Antidiscrimination Doctrine, Feminist Theory and Antiracist Politics. University of Chicago Legal Forum.

- Crouse, D.L., Pinault, L., Balram, A., Hystad, P., Peters, P.A., Chen, H., Donkelaar, A. Van, Martin, R. V, Ménard, R., Robichaud, A., Villeneuve, P.J., 2017. Urban greenness and mortality in Canada's largest cities : a national cohort study. *Lancet Planet. Heal.* 1, e289-97. [https://doi.org/10.1016/S2542-5196\(17\)30118-3](https://doi.org/10.1016/S2542-5196(17)30118-3)
- Dadvand, P., Bartoll, X., Basagaña, X., Dalmau-Bueno, A., Martinez, D., Ambros, A., Cirach, M., Triguero-Mas, M., Gascon, M., Borrell, C., Nieuwenhuijsen, M.J., 2016. Green spaces and General Health : Roles of mental health status , social support , and physical activity. *Environ. Int.* 91, 161–167. <https://doi.org/10.1016/j.envint.2016.02.029>
- Dadvand, P., de Nazelle, A., Figueras, F., Basagaña, X., Su, J., Amoly, E., Jerrett, M., Vrijheid, M., Sunyer, J., Nieuwenhuijsen, M.J., 2012a. Green space, health inequality and pregnancy. *Environ. Int.* 40, 110–115. <https://doi.org/10.1016/j.envint.2011.07.004>
- Dadvand, P., Sunyer, J., Basagaña, X., Ballester, F., Lertxundi, A., Fernández-Somoano, A., Estarlich, M., García-Esteban, R., Méndez, M.A., Nieuwenhuijsen, M.J., 2012b. Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environ. Health Perspect.* 120, 1481–1487.
- Dadvand, P., Wright, J., Martinez, D., Basagaña, X., Mceachan, R.R.C., Cirach, M., Gidlow, C.J., Hoogh, K. De, Gra, R., Nieuwenhuijsen, M.J., 2014. Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status. *Environ. Int.* 71, 101–108. <https://doi.org/10.1016/j.envint.2014.06.010>
- de Vries, S., van Dillen, S.M.E., Groenewegen, P.P., Spreeuwenberg, P., 2013. Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. *Soc. Sci. Med.* 94, 26–33. <https://doi.org/https://doi.org/10.1016/j.socscimed.2013.06.030>
- de Vries, S., Verheij, R.A., Groenewegen, P.P., Spreeuwenberg, P., 2003. Natural environments - healthy environments ? An exploratory analysis of the relationship between greenspace and health. *Environ. Plan. A Econ. Sp.* 35, 1717–1731. <https://doi.org/10.1068/a35111>
- Deboosere, P., Eggerickx, T., Van Hecke, E., Wayens, B., 2009. The population of Brussels: a demographic overview [WWW Document]. Brussels Studies, Synopses. Available at: <http://journals.openedition.org/brussels/898> (accessed 7.05.2021).
- Eurostat, 2017. Sustainable development in the European Union: Monitoring Report on Progress Towards the SDGs in an EU context. Publications Office of the European Union, Luxembourg.
- Evans, C.R., 2019a. Modeling the intersectionality of processes in the social production of health inequalities. *Soc. Sci. Med.* 226, 249–253. <https://doi.org/https://doi.org/10.1016/j.socscimed.2019.01.017>
- Evans, C.R., 2019b. Reintegrating contexts into quantitative intersectional analyses of health inequalities. *Health Place* 60, 102214. <https://doi.org/https://doi.org/10.1016/j.healthplace.2019.102214>
- Evans, C.R., Williams, D.R., Onnela, J.-P., Subramanian, S. V, 2018. A multilevel approach to modeling health inequalities at the intersection of multiple social identities. *Soc. Sci. Med.* 203, 64–73. <https://doi.org/https://doi.org/10.1016/j.socscimed.2017.11.011>
- Galobardes, B., Shaw, M., Lawlor, D.A., Lynch, J.W., Smith, G.D., 2006. Indicators of socioeconomic position (part 1). *J Epidemiol Community Heal.* 60, 7–12. <https://doi.org/10.1136/jech.2004.023531>
- Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., 2016. Residential green spaces and mortality : A systematic review. *Environ. Int.* 86, 60–67.

<https://doi.org/10.1016/j.envint.2015.10.013>

- Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., 2015. Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces : A Systematic Review. *Int. J. Environ. Res. Public Health* 12, 4354–4379. <https://doi.org/10.3390/ijerph120404354>
- Gidlow, C., Johnston, L.H., Crone, D., Ellis, N., James, D., 2006. A systematic review of the relationship between socio-economic position and physical activity. *Health Educ. J.* 65, 338–367. <https://doi.org/10.1177/0017896906069378>
- Green, M.A., Evans, C.R., Subramanian, S. V, 2017. Can intersectionality theory enrich population health research? *Soc. Sci. Med.* 178, 214–216. <https://doi.org/https://doi.org/10.1016/j.socscimed.2017.02.029>
- Hooyberghs, J., Mensink, C., Dumont, G., Fierens, F., 2006. Spatial interpolation of ambient ozone concentrations from sparse monitoring points in Belgium. *J. Environ. Monit.* 8, 1129–1135. <https://doi.org/10.1039/b612607n>
- Hughey, S.M., Kaczynski, A.T., Child, S., Moore, J.B., Porter, D., Hibbert, J., 2017. Green and lean: Is neighborhood park and playground availability associated with youth obesity? Variations by gender, socioeconomic status, and race/ethnicity. *Prev. Med.* 95, S101–S108. <https://doi.org/10.1016/j.ypmed.2016.11.024>
- Imai, K., Keele, L., Tingley, D., 2010. A General Approach to Causal Mediation Analysis. *Psychol Methods* 15, 309–334. <https://doi.org/10.1037/a0020761>
- IOM (International Organization for Migration), 2015. World Migration Report 2015. Geneva: IOM.
- James, P., Banay, R.F., Hart, J.E., Laden, F., 2015. A Review of the Health Benefits of Greenness. *Curr. Epidemiol. Reports* 2, 131–142. <https://doi.org/10.1007/s40471-015-0043-7>
- James, P., Hart, J.E., Banay, R.F., Laden, F., 2016. Exposure to Greenness and Mortality in a Nationwide Prospective Cohort Study of Women. *Environ. Health Perspect.* 124, 1344–1352.
- Jylhä, M., 2009. What is self-rated health and why does it predict mortality? Towards a unified conceptual model. *Soc. Sci. Med.* 69, 307–316. <https://doi.org/10.1016/j.socscimed.2009.05.013>
- Kapilashrami, A., Hill, S., Meer, N., 2015. What can health inequalities researchers learn from an intersectionality perspective? Understanding social dynamics with an inter-categorical approach? *Soc. Theory Heal.* 13, 288–307. <https://doi.org/10.1057/sth.2015.16>
- Klompmaaker, J.O., Janssen, N.A.H., Bloemsma, L.D., Gehring, U., Wijga, A.H., van den Brink, C., Lebret, E., Brunekreef, B., Hoek, G., 2019. Residential surrounding green, air pollution, traffic noise and self-perceived general health. *Environ. Res.* 179, 108751. <https://doi.org/https://doi.org/10.1016/j.envres.2019.108751>
- Krieger, N., 2001. A glossary for social epidemiology. *J. Epidemiol. Community Health* 55, 693–700.
- Lefebvre, W., Vranckx, S., 2013. Validation of the IFDM-model for use in urban applications: study accomplished in the framework of the ATMOSYS-project. 2013/RMA/R/56. Mol, Belgium.
- LeVasseur, M.T., Kelvin, E.A., Grosskopf, N.A., 2013. Intersecting Identities and the Association Between Bullying and Suicide Attempt Among New York City Youths: Results From the 2009 New York City Youth Risk Behavior Survey. *Am. J. Public Health* 103, 1082–1089. <https://doi.org/10.2105/AJPH.2012.300994>
- Maas, J., Verheij, R.A., Groenewegen, P.P., De Vries, S., Spreeuwenberg, P., 2006. Green space, urbanity, and health: how strong is the relation ? *J. Epidemiol. Community Health* 60, 587–592. <https://doi.org/10.1136/jech.2005.043125>

- Maas, J., Verheij, R.A., Vries, S. De, Spreeuwenberg, P., Schellevis, F.G., Groenewegen, P.P., 2009. Morbidity is related to a green living environment. *J. Epidemiol. Community Heal.* 63, 967–973. <https://doi.org/10.1136/jech.2008.079038>
- Marmot, M., Allen, J., Boyce, T., Goldblatt, P., Morrison, J., 2020. Health equity in England: the Marmot review 10 years on. London: Institute of Health Equity.
- McCall, L., 2005. The complexity of intersectionality. *Signs.* 30(3), 1771–1800.
- McEachan, R.R.C., Prady, S.L., Smith, G., Fairley, L., Cabieses, B., Gidlow, C., Wright, J., Dadvand, P., Gent, D. Van, Nieuwenhuijsen, M.J., Royal, B., 2016. The association between green space and depressive symptoms in pregnant women : moderating roles of socioeconomic status and physical activity. *J. Epidemiol. Community Heal.* 70, 253–259. <https://doi.org/10.1136/jech-2015-205954>
- McEachan, R.R.C., Yang, T.C., Roberts, H., Pickett, K.E., Arseneau-powell, D., Gidlow, C.J., Wright, J., 2018. Availability, use of, and satisfaction with green space, and children’s mental wellbeing at age 4 years in a multicultural, deprived, urban area: results from the Born in Bradford cohort study. *Lancet Planet. Heal.* 2, e244–e254. [https://doi.org/10.1016/S2542-5196\(18\)30119-0](https://doi.org/10.1016/S2542-5196(18)30119-0)
- Merlo, J., Mulinari, S., Wemrell, M., Subramanian, S. V, Hedblad, B., 2017. The tyranny of the averages and the indiscriminate use of risk factors in public health: The case of coronary heart disease. *SSM - Popul. Heal.* 3, 684–698. <https://doi.org/https://doi.org/10.1016/j.ssmph.2017.08.005>
- Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities : an observational population study. *Lancet* 372, 1655–1660. [https://doi.org/10.1016/S0140-6736\(08\)61689-X](https://doi.org/10.1016/S0140-6736(08)61689-X)
- Nieuwenhuijsen, M.J., Khreis, H., Triguero-Mas, M., Gascon, M., Dadvand, P., 2017. Fifty Shades of Green. Pathway to Healthy Urban Living. *Epidemiology* 28, 63–71. <https://doi.org/10.1097/EDE.0000000000000549>
- Orban, E., Sutcliffe, R., Dragano, N., 2017. Residential Surrounding Greenness , Self-Rated Health and Interrelations with Aspects of Neighborhood Environment and Social Relations. *J. Urban Heal.* 94, 158–169. <https://doi.org/10.1007/s11524-016-0112-3>
- Orioli, R., Antonucci, C., Scortichini, M., Cerza, F., Marando, F., Ancona, C., Manes, F., Davoli, M., Michelozzi, P., Forastiere, F., Cesaroni, G., 2019. Exposure to Residential Greenness as a Predictor of Cause-Specific Mortality and Stroke Incidence in the Rome Longitudinal Study. *Environ. Health Perspect.* 127, 1–11.
- Reklaitiene, R., Grazuleviciene, R., Dedele, A., Virviciute, D., Vensloviene, J., Tamosiunas, A., Luksiene, D., Sapranaviciute-zabazlajeva, L., Radisauskas, R., Bernotiene, G., Bobak, M., Mark, J., Publica, S., 2014. The relationship of green space, depressive symptoms and perceived general health in urban population. *Scand. J. Public Health* 42, 669–676. <https://doi.org/10.1177/1403494814544494>
- Richardson, E.A., Mitchell, R., 2010. Gender differences in relationships between urban green space and health in the United Kingdom. *Soc. Sci. Med.* 71, 568–575. <https://doi.org/10.1016/j.socscimed.2010.04.015>
- Rigolon, A., 2016. A complex landscape of inequity in access to urban parks : A literature review. *Landsc. Urban Plan.* 153, 160–169. <https://doi.org/10.1016/j.landurbplan.2016.05.017>
- Rojas-Rueda, D., Nieuwenhuijsen, M.J., Gascon, M., Perez-Leon, D., Mudu, P., 2019. Green spaces and mortality : a systematic review and meta-analysis of cohort studies. *Lancet Planet. Heal.* 3, e469–e477. [https://doi.org/10.1016/S2542-5196\(19\)30215-3](https://doi.org/10.1016/S2542-5196(19)30215-3)
- Science for Environment Policy, 2016. Links between noise and air pollution and socioeconomic status.

- In-depth Report 13 produced for the European Commission, DG Environment by the Science Communication Unit. UWE, Bristol. <https://doi.org/10.2779/200217>
- Scott, N.A., Siltanen, J., 2017. Intersectionality and quantitative methods: assessing regression from a feminist perspective. *Int. J. Soc. Res. Methodol.* 20, 373–385. <https://doi.org/10.1080/13645579.2016.1201328>
- Stafford, M., Cummins, S., Macintyre, S., Ellaway, A., Marmot, M., 2005. Gender differences in the associations between health and neighbourhood environment. *Soc. Sci. Med.* 60, 1681–1692. <https://doi.org/10.1016/j.socscimed.2004.08.028>
- Sugiyama, T., Leslie, E., Owen, N., 2008. Associations of neighbourhood greenness with physical and mental health : do walking , social coherence and local social interaction explain the relationships ? *J Epidemiol Community Heal.* 62, e9. <https://doi.org/10.1136/jech.2007.064287>
- Sugiyama, T., Villanueva, K., Knuiman, M., Francis, J., Foster, S., Wood, L., Giles-corti, B., 2016. Can neighborhood green space mitigate health inequalities ? A study of socio-economic status and mental health. *Health Place* 38, 16–21. <https://doi.org/10.1016/j.healthplace.2016.01.002>
- Triguero-Mas, M., Dadvand, P., Cirach, M., Martínez, D., Medina, A., Mompart, A., Basagaña, X., Gražulevičienė, R., Nieuwenhuijsen, M.J., 2015. Natural outdoor environments and mental and physical health : Relationships and mechanisms. *Environ. Int.* 77, 35–41. <https://doi.org/10.1016/j.envint.2015.01.012>
- UNESCO Institute for Statistics (UIS), 2012. International Standard Classification of Education. ISCED 2011. Montreal, Canada.
- Van de Voorde, T., 2016. Spatially explicit urban green indicators for characterizing vegetation cover and public green space proximity : a case study on Brussels , Belgium. *Int. J. Digit. Earth* 0, 1–16. <https://doi.org/10.1080/17538947.2016.1252434>
- Van de Voorde, T., Canters, F., Chan, J.C., 2010. Mapping update and analysis of the evolution of non-built (green) spaces in the Brussels Capital Region. *ActuaEvol/09 Final Report*. Brussels.
- Van Den Berg, M., Wendel-Vos, W., Van Poppel, M., Kemper, H., Van Mechelen, W., Maas, J., 2015. Health benefits of green spaces in the living environment : A systematic review of epidemiological studies. *Urban For. Urban Green.* 14, 806–816. <https://doi.org/10.1016/j.ufug.2015.07.008>
- Van Dillen, S.M.E., De Vries, S., Groenewegen, P.P., Spreeuwenberg, P., 2012. Greenspace in urban neighbourhoods and residents' health : adding quality to quantity. *J Epidemiol Community Heal.* 66, 1–5. <https://doi.org/10.1136/jech.2009.104695>
- Van Hamme, G., Grippa, T., Van Criekingen, M., 2016. Migratory movements and dynamics of neighbourhoods in Brussels. *Brussels Stud.* <https://doi.org/10.4000/brussels.1338>
- Vienneau, D., Hoogh, K. De, Faeh, D., Kaufmann, M., Marc, J., Rösli, M., Snc, T., Group, S., 2017. More than clean air and tranquillity : Residential green is independently associated with decreasing mortality. *Environ. Int.* 108, 176–184. <https://doi.org/10.1016/j.envint.2017.08.012>
- Villeneuve, P.J., Jerrett, M., Su, J.G., Burnett, R.T., Chen, H., Wheeler, A.J., Goldberg, M.S., 2012. A cohort study relating urban green space with mortality in Ontario, Canada. *Environ. Res.* 115, 51–58. <https://doi.org/10.1016/j.envres.2012.03.003>
- Weier, J., Herring, D., 2000. Measuring Vegetation (NDVI & EVI) [WWW Document]. URL <https://earthobservatory.nasa.gov/features/MeasuringVegetation> (accessed 7.4.19).
- Wemrell, M., Mulinari, S., Merlo, J., 2017. Intersectionality and risk for ischemic heart disease in Sweden: Categorical and anti-categorical approaches. *Soc. Sci. Med.* 177, 213–222. <https://doi.org/https://doi.org/10.1016/j.socscimed.2017.01.050>

WHO, 2016. ICD-10 Version:2016 [WWW Document]. URL <https://icd.who.int/browse10/2016/en> (accessed 10.9.19).