Does Living near Greener Areas in Cities Reduce Cause-Specific Mortality? A Longitudinal Follow-up Study in the Brussels Capital Region

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Background: A wide range of benefits are attributed to urban green spaces (UGS); benefits that could help dealing with upcoming societal challenges in cities, such as sustainable urban development and mitigation of climate change effects. Among the benefits, UGS could positively impact the health and well-being of residents through increased biodiversity, reduced temperature and noise, air particle filtration, stress reduction and creating natural spaces for physical activity and social cohesion. In this sense, there is growing evidence of a protective effect of living near greener areas on several health outcomes, such as reduced mental disorders or obesity. A recent body of literature has used prospective longitudinal studies based on large national mortality registers to assess the relationship between green spaces and specific causes of mortality, suggesting a stronger reduction on non-malignant respiratory disease and cardiovascular disease mortality. The aim of this study was to assess the association between residential greenness – measured using several dimensions – and cause-specific mortality in a study population of around 700,000 individuals officially residing in the Brussels Capital Region (BCR) during the follow-up period 2001-2016.

Methods: This study used the Belgian National Mortality Database, a linkage between the 2001 Belgian census and register data on emigration and mortality for the follow-up period from the 1st of October 2001 until the 31st of December 2016. Causes of death were registered using the 10th revision of the International Classification of Disease (ICD-10). The 2001 Belgian census contains a wide set of demographic and socio-economic variables for the total population officially residing in Belgium. Besides, the reference person of the household (as stated in the census: the person in charge of the administrative procedures within the household) had to fill in a separate questionnaire about his/her housing and neighbourhood characteristics (perceived quality of green spaces, air pollution or cleanliness). Several environmental indicators were linked to the residential address of each individual in the

National Mortality Database. We selected indicators for which the year of measurement was as closest to the middle of the follow-up period as possible, in order to capture representative mean values for the period. Nevertheless, noise pollution indicators were used although they did not meet this criterium of temporality, since it is unlikely that the distribution has changed notably. Residential greenness was measured through three indicators: (1) the Normalized Difference Vegetation Index (NDVI); (2) the Urban Atlas (UA) map; and (3) the percentage of reference persons who reported high quality of green spaces in the statistical ward. NDVI is a measure of green density on a land surface based on the reflectance of visible and near-infrared parts of the sunlight spectrum. A formula is applied to satellite images to obtain values ranging from 0 to 1, with 0 indicating no green and +1 representing the maximum density of green leaves. This study used a set of atmospherically corrected satellite images from the Landsat-7 for the summer periods of 2004–2006, with a 30x30m resolution. NDVI values were assigned to each individual in the census through the XY coordinates of his/her residential address. The percentage of total green was calculated using the 2006 Urban Atlas (UA), a land-use classification map with a 25x25m resolution. In this case, the reference point was not the residential address, but the centroids of the corresponding grids from the UA map corresponding to it. For both indicators, we obtained the quantity of residential green for three buffers: 300m, 500m and 1000m. Finally, we calculated the percentage of reference persons in each statistical ward who in 2001 reported very good quality of green spaces in their neighbourhoods. Air and noise pollution estimates were also linked to the residential address of each individual. For air pollution we used 2005 high resolution data provided by the Belgian Interregional Environment Agency (IRCEL-CELINE). Annual mean concentrations ($\mu g/m^3$) of particulate matter with an aerodynamic diameter smaller than 10µm (PM_{10}) and than 2.5 µm ($PM_{2.5}$), nitrogen dioxide (NO_2) and black carbon (BC) were assessed in the analyses. Data on 2016 noise pollution was provided by Brussels Environment, the administration for energy and environment in the Brussels Capital Region. We used daily average noise levels (L_{den}) of multi-exposure transportation noise (roads, trains and airplanes) in a decibel scale (dB), corrected for the evening and night noise levels through a 5dB and 10dB increase, respectively, due to the greater nuisance experienced when exposed to noise at those hours. We assessed specific causes of death for the follow-up period 2001-2016: all cardiovascular diseases (ICD-10: I10-I69); ischemic heart diseases (ICD-10: I20-I25); stroke (ICD-10: I60-I64); cerebrovascular disease (ICD-10: I60-I69); hypertension-related disease (ICD-10: I10-I15); all cardiovascular plus diabetes (ICD-10: I10-I69; E08-E13); all respiratory diseases (ICD-10: J00-J99); chronic obstructive pulmonary disease (COPD) (ICD-10: J40-J47); and all respiratory but COPD (ICD-10: J40-J47). Covariates included age (both as continuous and as categorical: 16-24 years, 25-39 years, 40-64 years, 65-80 years); gender; highest educational attainment (according to the International Standard Classification of Education: tertiary [levels 5-8], higher secondary [levels 3-4], lower secondary [level 2], low/no education [levels 0-1], unknown); activity status (student, employed, unemployed, inactive, retired, unknown); housing tenure (owner, tenant, unknown); household composition (single, cohabiting); migrant background (Belgian, other high-income country [HIC], Moroccan,

Turkish, other low- and middle-income country [LMIC], other); and area-level socio-economic status (the percentage of unemployed in the total working population at the statistical ward level). The association between the indicators of residential greenness (NDVI, percentage of total green and percentage of reference persons reporting very good quality of green spaces in the neighbourhood) and cause-specific mortality was assessed using Cox proportional hazards models, with age as the underlying time scale, to obtain Hazard Ratios (HR) and their 95% confidence intervals (95%CI). Observations were censored when emigration, death or end of the follow-up occurred. NDVI and percentage of total green were transformed in order to account for increases of an interquartile range (IQR) of green. Confounding variables were included in the model by stepwise entry to study the cumulative effect of their inclusion on the association. Models were adjusted by age, gender, highest educational attainment, occupation, housing tenure, household composition, migrant background, area-level SES, air pollutant concentrations and multiple noise exposure L_{den}. For air pollutant concentrations we assessed increments of 10 μg/m^3 for NO_2 and PM_{10}, 5 μg/m^3 for $PM_{2.5}$ and 1 μg/m^3 for BC. We accounted for IQR increases of multi-exposure daily average levels of noise pollution. Due to high correlation, only one indicator of each environmental dimension was included per model. We assessed potential effect modification by age, gender, highest educational attainment, occupation and migrant background through the inclusion of interaction terms with each indicator of residential greenness in the fully adjusted model and through stratification.

Results: We included 735,020 individuals aged between 16 and 80 years old and officially residing in the Brussels Capital Region in 2001. Individuals with missing information on the residential living environment variables were excluded from the analyses. During the follow-up period 2001-2016, 13.6% of the study population emigrated from the BCR (N=99,961). Among those who did not emigrate, 15.3% (N=96,992) died from a natural cause, 3.4% (21,575) died due to cardiovascular disease, and 1.4% (N=8,756) died from non-malignant respiratory diseases. The mean age at baseline was 43 years old. The study population was mainly composed of Belgians (52%), tertiary educated (28%), employed (43%) and cohabiting (58%). The median value for NDVI within 300-m was 0.41 (IQR: 0.32 – 0.52), for percentage of total green within 300-m it was 4.42% (IQR: 0 – 11.50%) and for percentage of households reporting very good quality of surrounding green spaces was 23.54 (IQR: 10.24 – 40.49%). NDVI within 300-m correlated stronger with percentage of households reporting very good quality of surrounding green spaces (r= 0.8057) than with percentage of total green in a 300-m buffer (r=0.5647). The stronger correlation with residential greenness indicators was found between $PM_{2.5}$ and NDVI within 300-m, although this was moderate (r=-0.6727). Night noise levels showed very weak correlations with all the indicators, and, in the case of Urban Atlas, these were positive. Fully adjusted Cox models showed that IQR increases of NDVI within 300-m were inversely associated with cardiovascular (HR: 0.94, 95%CI: 0.92-0.97), cerebrovascular (HR: 0.93, 95%CI: 0.88-0.98) and respiratory diseases (HR: 0.92, 95%CI: 0.88-0.96). No significant associations were found for ischemic heart disease mortality. Similar results were found for IQR increases on the percentage of households reporting very good quality of surrounding green spaces. For the percentage of total green within 300-m of the residential address no significant associations were found for any cause of mortality after the inclusion in the model of the percentage of unemployed at the area-level. Regarding the effect modification analyses by age, gender, highest educational attainment, occupation and migrant background, we did not find many significant results when including the interaction terms with residential greenness. For cardiovascular disease mortality, we found a significant protective effect of residential greenness only among the elderly (for NDVI within 300-m: HR: 0.94, 95%CI: 0.91-0.97) and the retired. For ischemic heart disease mortality, we only found a protective effect of residential greenness among individuals with no/low education (for NDVI within 300-m: HR: 0.93, 95%CI: 0.86-0.99) and unknown education (HR: 0.89, 95%CI: 0.80-0.99). Inverse associations were also found for cerebrovascular disease mortality among the higher educated and the Belgians, but the interaction terms were not significant.

Conclusions: This is the first study of the association between residential greenness and cause-specific mortality using a subjective indicator aggregated at the area level to assess the exposure to green. Interestingly, it was strongly correlated to NDVI, which is a non-specific indicator including all types of green, and both yielded similar results. These two indicators were associated with reduced mortality for cardiovascular, cerebrovascular and respiratory diseases in a follow-up study in the Brussels Capital Region. Residential greenness was only related to a reduction on ischemic heart disease mortality among the low/no educated. Further analyses are needed in order to understand potential mechanisms driving this relationship.