**Associations of public parks, greenness, and blue space with cardiovascular and respiratory disease hospitalization in the US Medicare cohort**

**Authors and affiliations:**

Jochem O Klompmaker a, b, Francine Laden a, b, c, Matthew H E M Browning d, Francesca Dominici e, S Scott Ogletree f, Alessandro Rigolon g, Jaime E Hart a, b\*, Peter James a, h\*

*a Department of Environmental Health, Harvard T. H. Chan School of Public Health, Boston, Massachusetts 02115, USA*

*b Channing Division of Network Medicine, Department of Medicine, Brigham and Women’s Hospital, Boston, Massachusetts 02115, USA*

*c Department of Epidemiology, Harvard T. H. Chan School of Public Health, Boston, Massachusetts 02115, USA*

*d Department of Parks, Recreation and Tourism Management, Clemson University, Clemson, South Carolina 29634, USA*

*e Department of Biostatistics, Harvard T.H. Chan School of Public Health, Boston, Massachusetts 02115, USA*

*f OPENspace Research Centre, School of Architecture and Landscape Architecture, University of Edinburgh, Edinburgh, UK*

*g Department of City and Metropolitan Planning, The University of Utah, 375 South 1530 East, Salt Lake City, Utah 84112, USA*

*h Department of Population Medicine, Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, Massachusetts 02215, USA*

*\* Contributed equally as last author*

**Corresponding author:**

Jochem O Klompmaker, PhD

jklompmaker@hsph.harvard.edu

Department of Environmental Health, Harvard T. H. Chan School of Public Health, Landmark Center, 401 Park Drive, Boston Massachusetts 02215, USA

Channing Division of Network Medicine, Department of Medicine, Brigham and Women’s Hospital, 181 Longwood Avenue, Boston, Massachusetts 02115, USA

**Abstract**

**Background:** Natural environments have been linked to decreased risk of cardiovascular disease (CVD) and respiratory disease (RSD) mortality. However, few cohort studies have looked at associations of natural environments with CVD or RSD hospitalization. Our aim was to evaluate these associations in a cohort of Medicare beneficiaries (~63 million individuals).

**Methods:** Our open cohort included all fee-for-service Medicare beneficiaries (2000-2016), aged ≥65, living in the contiguous U.S. We assessed zip code-level average percent public park cover, greenness, and percent blue space cover. Cox-equivalent Poisson models were used to estimate associations of the exposures with first CVD and RSD hospitalization in the full cohort and among those living in urban areas.

**Findings:** Greenness was weakly negatively correlated with percent public park cover (Spearman rho =   
-0·23). After adjustment for potential confounders, an IQR increase in greenness was negatively associated with CVD (HR: 0·97, 95%CI: 0·96, 0·97), but not with RSD hospitalization. In urban zip codes (≥1000 persons/mile2), greenness was positively associated with RSD hospitalization. Percent public park cover was negatively associated with CVD and RSD hospitalization only for Medicaid eligible individuals and individuals living in low socioeconomic status neighborhoods in the urban population. Percent blue space cover was not associated with CVD or RSD hospitalization.

**Interpretation:** These results suggest that natural environments may benefit health; however, benefits may be limited to certain contexts and certain health outcomes.

**Funding:** This study was funded by R01 ES028033, R01 ES024332, P30 ES000002, R01 AG066793-01, and R01 HL150119.

**Research in context**

**Evidence before this study**

Greenness exposure has been linked to decreased risk of cardiovascular disease (CVD) and respiratory disease (RSD) mortality in several large cohort studies. However, few cohort studies have examined associations of natural environments with CVD hospitalization. To the best of our knowledge, there are no cohort studies that have evaluated associations of natural environments with RSD hospitalizations in adults.

In environmental health studies, a variety of measures of the natural environment have been used. Most studies focus on the availability of greenness as measured by satellite-based vegetation indices. These indices assess vegetation quantity but do not differentiate between types of green spaces (public parks, agricultural land, private yards) that may differ in their impact on health.

**Added value of this study**

We assessed three different features of the natural environment: percent public park cover, satellite-based greenness, and percent blue space cover. We examined associations of these exposures with first CVD and RSD hospitalization in a cohort of Medicare beneficiaries (~63 million individuals). Greenness was weakly negative correlated with percent public park cover. After adjustment for potential confounders, percent public park cover and percent blue space cover were not associated with CVD or RSD hospitalization in the full or urban population. However, percent public park cover was negatively associated with CVD and RSD hospitalization for individuals of low socioeconomic status living in urban areas. We observed that greenness was negatively associated with CVD. No protective association of greenness with RSD hospitalization was observed in the full population. In the urban population, greenness was positively associated with RSD hospitalization.

**Implications of all the available evidence**

Our study suggests that greenness does not represent public parks well at the zip code level. Further, our results suggest that natural environments may benefit cardiorespiratory health; however, benefits may be limited to certain contexts and certain health outcomes.

**Introduction**

Numerous studies have reported potential beneficial health effects of exposure to natural environments.1,2 Several potential pathways underlying associations of natural environments to health have been suggested. Natural environments may reduce exposure to harmful environmental exposures (e.g., air pollution, noise), can be a resource for stress reduction and attention restoration, and can encourage physical activity and social interactions.2,3 On the other hand, vegetation may adversely affect health by releasing pollen and volatile organic compounds (VOCs).3,4

Many measures of the natural environment have been used in epidemiologic studies. Most studies focus on availability of greenness, measured by satellite-based vegetation indices such as the Normalized Difference Vegetation Index (NDVI).5 These vegetation indices assess the quantity of green vegetation but do not differentiate vegetation quality or green space type. Public parks, agricultural lands, uncultivated lands, and private yards are generally captured by vegetation indices but may differ in their impact on health. Public parks, for example, provide suitable spaces for physical activities and social gatherings and are publicly accessible, in contrast to agricultural or private lands. Exposure to blue space (e.g. rivers, lakes, oceans) has received less attention in comparison to green space but can be potentially helpful to de-stress, calm and relax.6,7

Exposure to green space has been linked to decreased risk of cardiovascular disease (CVD) and respiratory disease (RSD) mortality in several large cohort studies.8–11 Only a few cohort studies observed negative associations between greenness and CVD incidence.12–14 To the best of our knowledge, there are no cohort studies that have evaluated associations of green space with RSD incidence in adults. Some cross-sectional studies reported a beneficial association between residential greenness and RSD, such as asthma or COPD, in adults.15–18 However, a study from China observed positive associations between neighborhood greenness and COPD prevalence.4 Evidence of associations between blue space exposure and CVD outcomes and all-cause mortality is not consistent.19 A study in Spain observed an increased risk between exposure to blue space and all-cause mortality,20 whereas a study in Canada observed decreased risks between exposure to blue space and all-cause, CVD and RSD mortality.21

Our aim was to evaluate associations of features of natural environments with CVD and RSD hospitalization in a cohort of all fee-for-service Medicare beneficiaries living in the contiguous U.S. from 2000 through 2016 (~63 million individuals). We assessed percent public park cover, greenness and percent blue space cover for each zip code in the contiguous U.S. As reviews reported stronger effects of natural environments in urban areas and among low socioeconomic status (SES) individuals,2,22,23 we also evaluated associations in beneficiaries living in urban zip codes (≥ 1000 persons/mile2) and in different neighbourhood SES (nSES) zip codes.

**Methods**

*Study population*

To create an open cohort, data were derived from the Medicare denominator and Medicare Provider Analysis and Review (MEDPAR) files. Medicare is a national health insurance program that provides health insurance for Americans aged 65 and older and for younger people with disability status. Our cohort included all fee-for-service Medicare beneficiaries, aged ≥65 years, living in the contiguous U.S. from January 1, 2000-December 31, 2016. For each beneficiary, follow-up started on January 1st 2000 or January 1st of the year following entry into the cohort. Each beneficiary was followed until the first hospital admission for the outcome of interest, censoring, end of the follow-up, or death.

*Outcome definition*

Hospital admissions for all Medicare fee-for-service beneficiaries from 2000 through 2016 were available in MEDPAR. From 2000 through the third quarter of 2015, the *International Classification of Disease, Ninth Edition* (ICD-9) codes were used. From the fourth quarter of 2015, ICD-10 (from the *Tenth Edition*) codes were used. We looked at first hospital admission with a primary discharge diagnosis of CVD (ICD-9: 390-459, ICD-10: I00-I99) or RSD (ICD-9: 460-519, ICD-10: J00-J99). Separate cohorts for CVD and RSD hospitalizations were created.

*Exposure assessment*

As we only had information about the residential zip code of each beneficiary, we assessed exposures on zip code level. Public park cover was based on the cross-sectional United States Geological Survey Protected Areas Database of the U.S. (PAD-US) V2.1 (2020). We selected all land types that are likely to be known and used by the general public for outdoor recreation. To assess zip code-level public park cover, we calculated the percent public park cover for each zip code.

The Normalized Difference Vegetation Index (NDVI), an indicator of greenness, was estimated using satellite imagery. The NDVI is calculated as the ratio between the red and near infrared values.24 NDVI ranges from -1 to 1 and values close to 1 correspond to areas with complete coverage by live vegetation, values close to zero correspond to areas without live vegetation and negative values correspond to water. Using Google Earth Engine,25 we made cloud-free NDVI composite maps (based on Landsat 7 and Landsat 8 images) for the contiguous U.S . After setting negative NDVI values to zero, we calculated the spatially-weighted mean summer NDVI for each zip code in the U.S. for each year.

We estimated blue space using satellite imagery based on the Joint Research Centre's Global Surface Water Dataset.26 This dataset contains information about the location of surface water, based on Landsat 5, 7, and 8 images from 1984 to 2018. Information was aggregated over the entire time period and not available for each year. As zip codes are used for postal services, adjacent water bodies such as rivers, lakes and oceans are not always included in zip code areas. Therefore, we calculated spatially weighted mean blue space cover of zip codes with a 1000 m buffer around each zip code.

Detailed information about the exposures can be found in the supplementary methods (S1. Exposure assessment).

*Covariates*

For each beneficiary, information about year of entry, age at entry, sex, race, Medicaid eligibility [a proxy for low SES], and zip code of residence was derived from the Medicare beneficiary file. As a proxy for nSES, we used eight zip code-level covariates from the U.S. Census and American Community Survey. We linked percent of the population that were ever smokers (based on the county level), derived from the nationwide Behavioural Risk Factor Surveillance System (BRFSS). Further, we assigned US census regions (West, Midwest, Northeast, South), and zip code-level particulate matter less than 2.5 microns (PM2.5), nitrogen dioxide (NO2), summer maximum daily temperature, ambient specific humidity, and total precipitation. The covariates are described in more detail in the supplementary methods (S2. Covariates).

*Statistical analyses*

We applied a Cox-equivalent re-parameterized Poisson model to overcome computational challenges due to our large cohort. We aggregated all beneficiaries within the same zip code in a specific year, with the same age (2-year categories), sex, race, Medicaid eligibility and year of follow-up and treated them as one single grid cell. We fitted a stratified quasi-Poisson model to estimate associations with the rate of first CVD and RSD hospitalizations. The count of CVD and RSD related first hospitalizations in each grid cell was the dependent variable, using the corresponding total person-time in each grid cell as the offset. To account for within zip code correlated observations across years, an m-out-n bootstrap method using zip code units was used to calculate statistically robust confidence intervals (CIs). All hazard ratios (HRs) were expressed per IQR increase (based on the full CVD cohort). The Cox-equivalent re-parameterized Poisson approach is described in more detail elsewhere.27

To evaluate the impact of potential confounders, we fitted models with increasing degrees of covariate adjustment. In our main model we included all three exposures simultaneously and adjusted for calendar year, region, nSES, smoking status, an offset for total person-time and strata for all possible combinations of sex, race, Medicaid Eligibility, age, and follow-up year. We evaluated the shape of the exposure-response curves for each exposure with natural splines with 2 or 3 degrees of freedom. In addition, we estimated associations of public park cover, greenness and blue space cover for individuals living in urban zip codes (population density ≥ 1000 persons/mile2). To evaluate whether associations were modified by individual demographics, region, and nSES, we stratified our analyses by sex (male, female), age (<75 years, 75-84 years, ≥85 years), race (White, Black, other/unknown), Medicaid eligibility (eligible, not eligible), region (West, Midwest, Northeast, South) and tertiles of zip code-level percent below the poverty level, median home value, and median household income. For sensitivity analyses, we excluded beneficiaries who had their first CVD or RSD hospital admission within the first year of their follow-up and all records in the year 2000, to exclude potential prevalent CVD or RSD cases. We ran single-exposure models and additionally adjusted for zip code level NO2 and PM2.5. We also examined percent blue space cover without a 1000m buffer.

R software (R Project for Statistical Computing) version 3.6.1 were used for our analyses. The analyses were conducted on the Harvard Research Computing Environment, which is supported by the Institute for Quantitative Social Science at Harvard University.

*Role of funding source*

The funders had no role in the study design; in the collection, analysis and interpretation of data; in the writing of the report; or in the decision to submit the article for publication.

*Informed consent*

This study was approved by the institutional review board at the Harvard T H Chan School of Public Health and was exempt from informed consent requirements as a study of existing administrative data.

**Results**

In total 63,009,173 Medicare beneficiaries were included in the full cohort. We observed 18,610,833 first CVD hospital admissions in 401,315,016 person years and 9,741,992 first RSD hospital admissions in 453,244,756 person years. The vast majority of the individuals in the cohorts were White, not eligible for Medicaid, and between 65-74 years of age when they entered the study (Table 1). Percent public park cover was highest in the western U.S., while greenness was highest in the eastern U.S. (Figure 1). Median percent public park cover was lower in the full cohort (7·5 %) than the urban cohort (11·4 %), while median greenness was higher in the full cohort (0·52) than the urban cohort (0·39). Greenness was weakly negatively correlated with percent public park cover (Spearman rho = -0·23) and not correlated with percent blue space cover (Spearman Rho = 0·00, Figure S1). In the urban cohort, greenness was not correlated with percent public park cover (Spearman rho = 0·03).

*Associations in the full cohort*

Splines showed no or small deviations from linearity for the exposure-response curves (Figure S2). We observed negative associations of percent public park cover with CVD and RSD hospitalizations in our minimally adjusted model (Model 1, Figure S3). After adjustment for potential confounders, associations of percent public park cover attenuated to null (Table 2). For greenness, we observed weak positive associations with CVD and RSD hospitalization in our minimally adjusted model. In the fully adjusted model (Model 5), we found negative associations of greenness with CVD hospitalization (HR: 0·97, 95%CI: 0·96, 0·97, per IQR increase) but not with RSD hospitalization (HR: 0·99, 95%CI: 0·98, 1·00, per IQR increase). Percent blue space cover was not associated with CVD or RSD hospitalization.

In general, for percent public park cover and percent blue space cover, we did not observe a clear pattern of effect modification by individual demographics (Figure 2) or nSES (Figure 3) for CVD and RSD hospitalization. Negative associations of greenness with CVD hospitalization were stronger for individuals 85+ compared to 65+ or 75+ years, and for individuals not eligible for Medicaid compared to individuals eligible. We observed negative associations of greenness with CVD hospitalization for White and Black individuals, but positive associations for individuals of unknown/other race. Further, negative associations were observed for individuals living in the West and Northeast and positive in the South. For RSD hospitalization, we observed negative associations of greenness for females, Black individuals, and individuals living in the West or Midwest. Associations of greenness with CVD hospitalization became stronger with decreasing percent below the poverty levels (Figure 3).

*Associations in the urban cohort*

Associations of percent public park cover with CVD and RSD hospitalization in urban areas were negative in our minimally adjusted model and attenuated after adjustment for potential confounders (Figure S3, Table 2). Greenness was negatively associated with CVD hospitalization and positively associated with RSD hospitalization in our fully adjusted model. No associations for percent blue space cover were observed in urban areas.

Percent public park cover was negatively associated with CVD and RSD hospitalization for Medicaid eligible individuals, individuals with an unknown or other race, and individuals living in the lowest median household income tertile and in the highest percent below poverty tertile (Figure S4 and S5). In urban areas, negative associations of greenness with CVD hospitalization were stronger for the elderly and individuals not eligible for Medicaid, no association was observed for individuals eligible for Medicaid. We observed positive associations of greenness with RSD hospitalization for males, younger, Medicaid eligible, and White individuals. We observed negative associations of greenness in the West (for CVD and RSD hospitalization) and in the Midwest (for CVD hospitalization). No associations of greenness with RSD hospitalization were observed in zip codes with a high median household income and low percent below the poverty level.

*Sensitivity analyses*

In the full and urban cohort, we observed that associations were generally robust to additional adjustments for PM2.5, exclusion of potentially prevalent cases, and parameterizations of blue space (Table S2). Associations of single-exposure models were also similar. Additional adjustment for NO2 substantiallyattenuated associations of greenness with CVD and resulted in positive associations of greenness with RSD hospitalizations.

**Discussion**

In this study of over 63 million Medicare beneficiaries, we observed protective associations between greenness and CVD, but not RSD, hospitalizations. In the urban cohort, associations of greenness with RSD hospitalization were positive. There was no protective association between public park or blue space cover and CVD or RSD hospitalization in the full cohort. However, percent public park cover was negatively associated with CVD and RSD hospitalization for low-SES individuals in urban areas.

We observed a weak negative correlation between percent public park cover and greenness, indicating that greenness does not represent public parks well at the zip code level. This is likely because NDVI captures total greenness, and therefore includes all types of green areas, such as agriculture, forests, lawns, and yards. Moreover, not all public parks contain dense vegetation. In urban areas, the correlation between percent public park cover and greenness was close to null. This was somewhat unexpected as some urban greenness can be found in parks; however, urban parks may include paved paths and playgrounds that do not contain vegetation. Moreover, NDVI captures street and private greenery, which may constitute a large portion of the total greenness in urban areas. Not all types of greenery contribute equally to the NDVI, as it depends on the amount of aboveground photosynthetic biomass. Further, we note that correlations of percent public park cover and NDVI with some covariates, such as median home value, population density and NO2, differ in direction.

We observed negative associations of greenness with CVD hospitalization, in line with previous studies.12–14 Public park cover was not associated with CVD hospitalization. This is contrary to our expectations as public park cover could be expected to be a better indicator for green spaces suitable for physical activity and social gatherings, and therefore may have a stronger impact on health. However, after adjustment for NO2,the negative association of greenness with CVD hospitalization almost completely disappeared. So, there may not be true differences in associations with these exposures, but we also note that NO2 could be a mediator in the greenness-CVD hospitalization relation.

We observed positive associations of greenness with RSD hospitalization in the urban cohort, and in the full cohort after adjustment for NO2. This is in contrast to findings of some,15–18 but not all studies.4 The positive association with RSD hospitalization might be because vegetation can be a source of pollen and other respiratory irritants, such as VOCs.28 Emission of VOCs might be more strongly related to greenness compared to percent public park cover. Dominant vegetation types likely differ between regions; this may explain the differences of our findings with other studies and also the differences between the regional effect estimates for greenness. In the eastern U.S., isoprene and monoterpene emission from vegetation is generally high,29,30 and could explain the positive associations of greenness with RSD hospitalization in the South and Northeast.

We observed no protective association between percent public park cover or blue space and CVD or RSD hospitalization. This could be due to the absence of true associations in this study population, or methodological issues, such as our use of zip code-level exposure, characteristics of our study population, and adjustment for potential confounders. As we do not have information about the exact residential address of each beneficiary, we used zip code-level exposures. The median area of a zip code in the contiguous U.S. (in 2016) was about 107 km2 and in urban areas it was about 18 km2. This is substantially larger than the 300m (area: 0.28 km2), and 1000m (area: 3.14 km2) buffers commonly used in natural environment and health studies. Moreover, greenness and percent public park cover can differ substantially within a zip code, and beneficiaries living close to the border of their zip code can be exposed to greenness in neighboring zip codes. The lack of associations for percent blue space cover may be related to the limited variability. Moreover, we note that there could be several air pollution sources in/close to blue spaces that may balance out potential beneficial effects of blue space.

In the full and urban population, percent public park cover was generally negatively associated with CVD and RSD hospitalization for low SES individuals (Medicaid eligible individuals, individuals living in the lowest nSES tertile), but not for mid or high SES individuals. Associations of greenness with CVD hospitalization, on the other hand, were weaker/absent for low SES individuals and positive associations with RSD hospitalization were stronger for low SES individuals in the urban cohort. These findings are not consistent with a recent review that reported that beneficial effects of green space are stronger for low SES individuals than for high SES individuals and that protective effects for low SES groups were stronger for public green space than greenness.23 As parks are freely accessible, individuals of low SES may go there to work out, relax, and socially interact.

Our study has multiple strengths. We assessed public park cover, greenness and blue space for each zip code in the U.S. Percent public park cover, greenness and blue space were included simultaneously in our models, to estimate associations for each exposure independent of the other exposures. We included approximately 63 million Medicare fee-for-service beneficiaries living in the contiguous U.S. in our cohorts. The Medicare study population is a fairly representative sample of individuals aged 65+ years across the U.S. However, during our follow-up period, Medicare beneficiaries may have switched to managed care plans and back, which could have resulted in some missed cases in our data. We note that elderly may experience, perceive, and use nature differently than other age groups. Hence, findings may not be generalizable to younger populations. Our study also has some limitations, in addition to those discussed above. Natural environment indicators were assessed at the zip code level, which likely resulted in exposure measurement error. We had no information about quality and safety of parks, greenness and blue spaces and on whether blue spaces could be used for recreation. Blue space was based on satellite images from 1984 to 2018 years and public park cover was based on data from 2020. We assumed that the spatial distribution of these exposures was stable over time. We were unable to adjust for individual-level SES (other than Medicaid eligibility) and lifestyle factors, which may have resulted in an overestimation of the associations. However, we included various nSES measures, that are likely related to individual SES. Further, we note that some individuals may have had their first CVD or RSD hospitalization before they were eligible for Medicare.

In conclusion, we observed a protective effect of greenness on CVD hospitalization and indications of a harmful effect on RSD hospitalization. For individuals of low SES, we observed that percent public park cover, but not greenness, was negatively associated with CVD and RSD hospitalization in urban areas. Blue space was not associated with CVD or RSD hospitalization. These results suggest that natural environments may benefit health; however, benefits may be limited to certain contexts and certain health outcomes.

**Funding**

This study was supported by National Institute of Environmental Health Sciences (R01 ES028033, R01 ES024332, P30 ES000002), National Institute on Aging (R01 AG066793-01), and the National Heart, Lung, and Blood Institute (R01 HL150119).

**Data sharing statement**

The data used in this study will not be made available publicly or shared with other researchers because of restrictions in the data-use agreement with the Center for Medicare and Services (CMS). However, other investigators can apply to the CMS for their own data-use agreements to access the Medicare data. We used data from the Landsat satellites to assess greenness (NDVI) and blue space and from the Gridded Surface Meteorological dataset to assess specific humidity, temperature and precipitation. This data is freely available in Google Earth Engine. A statistical analysis plan is available from the corresponding author (jklompmaker@hsph.harvard.edu) on reasonable request.

**Declaration of interest**

We declare that we have no conflicts of interest.

**Literature**

1 Twohig-Bennett C, Jones A. The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environ Res* 2018; **166**: 628–37.

2 Fong KC, Hart JE, James P. A Review of Epidemiologic Studies on Greenness and Health: Updated Literature Through 2017. Curr. Environ. Heal. reports. 2018; **5**: 77–87.

3 Markevych I, Schoierer J, Hartig T, *et al.* Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environ Res* 2017; **158**: 301–17.

4 Fan J, Guo Y, Cao Z, *et al.* Neighborhood greenness associated with chronic obstructive pulmonary disease: A nationwide cross-sectional study in China. *Environ Int* 2020; **144**: 106042.

5 Labib SM, Lindley S, Huck JJ. Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environ Res* 2020; **180**: 108869.

6 McDougall CW, Quilliam RS, Hanley N, Oliver DM. Freshwater blue space and population health: An emerging research agenda. *Sci Total Environ* 2020; **737**: 140196.

7 White MP, Elliott LR, Gascon M, Roberts B, Fleming LE. Blue space, health and well-being: A narrative overview and synthesis of potential benefits. Environ. Res. 2020; **191**: 110169.

8 Vienneau D, Hoogh K de, Faeh D, *et al.* More than clean air and tranquillity: residential green is independently associated with decreasing mortality. *Environ Int* 2017; **108**: 176–84.

9 Crouse DL, Pinault L, Balram A, *et al.* Urban greenness and mortality in Canada’s largest cities: a national cohort study. *Lancet Planet Heal* 2017; **1**: e289–97.

10 Klompmaker JO, Janssen NAH, Bloemsma LD, *et al.* Effects of exposure to surrounding green, air pollution and traffic noise with non-accidental and cause-specific mortality in the Dutch national cohort. *Environ Heal 2021 201* 2021; **20**: 1–16.

11 Bauwelinck M, Casas L, Nawrot TS, *et al.* 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* 2021; **148**: 106365.

12 Chen H, Burnett RT, Bai L, *et al.* Residential Greenness and Cardiovascular Disease Incidence, Readmission, and Mortality. *Environ Health Perspect* 2020; **128**: 1–11.

13 Seo S, Choi S, Kim K, Kim SM, Park SM. Association between urban green space and the risk of cardiovascular disease: A longitudinal study in seven Korean metropolitan areas. *Environ Int* 2019; **125**: 51–7.

14 Dalton AM, Jones AP. Residential neighbourhood greenspace is associated with reduced risk of cardiovascular disease: A prospective cohort study. *PLoS One* 2020; **15**: e0226524.

15 Sarkar C, Zhang B, Ni M, *et al.* Environmental correlates of chronic obstructive pulmonary disease in 96 779 participants from the UK Biobank: a cross-sectional, observational study. *Lancet Planet Heal* 2019; **3**: e478–90.

16 Maas J, Verheij RA, De Vries S, Spreeuwenberg P, Schellevis FG, Groenewegen PP. Morbidity is related to a green living environment. *J Epidemiol Community Heal* 2009; **63**: 967–73.

17 Alcock I, White M, Cherrie M, *et al.* Land cover and air pollution are associated with asthma hospitalisations: A cross-sectional study. *Environ Int* 2017; **109**: 29–41.

18 Xiao Y, Gu X, Niu H, *et al.* Associations of residential greenness with lung function and chronic obstructive pulmonary disease in China. *Environ Res* 2022; **209**: 112877.

19 Georgiou M, Morison G, Smith N, Tieges Z, Chastin S. Mechanisms of impact of blue spaces on human health: A systematic literature review and meta-analysis. *Int J Environ Res Public Health* 2021; **18**: 1–41.

20 Nieuwenhuijsen MJ, Gascon M, Martinez D, *et al.* Air Pollution, Noise, Blue Space, and Green Space and Premature Mortality in Barcelona: A Mega Cohort. *Int J Environ Res Public Heal 2018, Vol 15, Page 2405* 2018; **15**: 2405.

21 Crouse DL, Balram A, Hystad P, *et al.* Associations between living near water and risk of mortality among urban Canadians. *Environ Health Perspect* 2018; **126**. DOI:10.1289/EHP3397.

22 Browning MHEM, Rigolon A, McAnirlin O, Yoon H (Violet). Where greenspace matters most: A systematic review of urbanicity, greenspace, and physical health. *Landsc Urban Plan* 2022; **217**: 104233.

23 Rigolon A, Browning MHEM, McAnirlin O, Yoon H. Green space and health equity: A systematic review on the potential of green space to reduce health disparities. *Int J Environ Res Public Health* 2021; **18**: 1–29.

24 NASA. Measuring Vegetation (NDVI & EVI). https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring\_vegetation\_2.php (accessed June 16, 2020).

25 Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sens Environ* 2017; **202**: 18–27.

26 Pekel JF, Cottam A, Gorelick N, Belward AS. High-resolution mapping of global surface water and its long-term changes. *Nature* 2016; **540**: 418–22.

27 Shi L, Wu X, Danesh Yazdi M, *et al.* Long-term effects of PM2·5 on neurological disorders in the American Medicare population: a longitudinal cohort study. *Lancet Planet Heal* 2020; **4**: e557–65.

28 Hanigan IC, Johnston FH. Respiratory hospital admissions were associated with ambient airborne pollen in Darwin, Australia, 2004–2005. *Clin Exp Allergy* 2007; **37**: 1556–65.

29 Li R, Pei S, Chen B, *et al.* Substantial undocumented infection facilitates the rapid dissemination of novel coronavirus (SARS-CoV-2). *Science (80- )* 2020; **368**: 489–93.

30 Millet DB, Jacob DJ, Folkert Boersma K, *et al.* Spatial distribution of isoprene emissions from North America derived from formaldehyde column measurements by the OMI satellite sensor. *J Geophys Res Atmos* 2008; **113**: 2307.

**Table 1. Descriptive statistics of all U.S. Medicare fee-for-service beneficiaries (n = 63,009,173) from 2000 through 2016.a**

|  |  |  |
| --- | --- | --- |
| **Individual-level covariates** | **Demographics at study entry** | **N (%)** |
| **Sex** | Female | 34,725,534 (55·1) |
| **Age entry** | 65-74 years | 48,240,802 (76·6) |
| 75-84 years | 10,819,118 (17·2) |
| 85+ years | 3,949,253 (6·3) |
| **Race** | White | 53,262,938 (84·5) |
| Black | 5,511,612 (8·7) |
| Other/unknown | 4,234,623 (6·7) |
| **Medicaid eligibility** | Not eligible | 55,164,043 (87·5) |
| Eligible | 7,845,130 (12·5) |
| **Region** | Northeast | 12,374,875 (19·6) |
|  | South | 24,085,710 (38·2) |
|  | Midwest | 15,254,270 (24·2) |
|  | West | 11,294318 (17·9) |
| **Zip code-level covariates a** | **Aggregated data (2000-2016)** | **Median (IQR)** |
| **Natural environment measures** | % Public park cover | 7·5 (15·9) |
|  | NDVI | 0·52 (0·27) |
|  | % Blue space cover (1000m buffer) | 0·5 (3·2) |
|  | % Blue space cover (no buffer) | 0·3 (1·3) |
| **US census covariates** | Population density (persons/mile2) | 517·4 (2919·0) |
|  | Median home value ($1,000) | 139·4 (145·3) |
|  | Median household income ($1,000) | 46·0 (24·9) |
|  | % with less than a high school degree | 24·7 (21·6) |
|  | % below the poverty level | 8·6 (8·2) |
|  | % owner-occupied housing units | 71·8 (21·4) |
|  | % Black | 3·7 (13·5) |
|  | % Hispanic | 5·0 (14·0) |
| **BRFSS covariate** | % ever smoked | 46·2 (9·1) |
| **Other environmental exposures** | summer temperature (°C) | 29·9 (5·2) |
|  | summer specific humidity (g of water vapor / kg of dry air) | 12·0 (4·0) |
|  | summer total precipitation (mm, daily total) | 3·1 (2·3) |
|  | PM2.5 (µg/m3) | 9·7 (4·0) |
|  | NO2 (ppb) | 16·3 (13·9) |

a Descriptive statistics of the zip code level covariates are given for the strata (aggregated data based on zip code, year, sex, race, Medicaid eligibility, 2-year categories of age at study entry and year of follow-up) based on the CVD cohort. Descriptive statistics of the zip code level covariates for the RSD cohort are shown in Table S1.

**Table 2. HRs of percent public park cover, NDVI and percent blue space cover with CVD and RSD hospitalization in the full and urban cohort of U.S. Medicare fee-for-service beneficiaries aged ≥65 years living in the contiguous U.S. from 2000 through 2016 (n = 63,009,173).a, b**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Exposure (IQR)** | **CVD hospitalization** | | **RSD hospitalization** | |
| **Full cohort** | **Urban cohort** | **Full cohort** | **Urban cohort** |
| **HR (95% CI)** | **HR (95% CI)** | **HR (95% CI)** | **HR (95% CI)** |
| **% Public park cover (15·9)** | 1·00 (0·99, 1·00) | 0·99 (0·99, 1·00) | 0·99 (0·99, 1·00) | 1·00 (0·99, 1·00) |
| **NDVI (0·27)** | 0·97 (0·96, 0·97) | 0·98 (0·97, 0·99) | 0·99 (0·98, 1·00) | 1·02 (1·00, 1·03) |
| **% Blue space cover (3·2)** | 1·00 (1·00, 1·00) | 1·00 (1·00, 1·00) | 1·00 (1·00, 1·00) | 1·00 (1·00, 1·00) |

a Associations are expressed per IQR increase of the CVD hospitalization (full) cohort. Models included percent public park cover, NDVI and percent blue space cover simultaneously. Models were adjusted for calendar year, region, U.S. census covariates, % ever smoked, summer temperature, summer specific humidity, summer total precipitation, an offset for total person-time and strata for all possible combinations of sex, race, Medicaid Eligibility, age at study entry (2-year categories), and follow-up year. Urban cohorts included all person years in zip codes with a population density of 1000+ persons/mile2.

b In the full cohorts, we observed 18,610,833 first CVD hospital admissions in 401,315,016 person years, 9,741,992 first respiratory disease hospital admissions in 453,244,756 person years. In the urban cohorts, we observed 8,354,677 first CVD hospital admissions in 185,252,789 person years, 4,387,395 first respiratory disease hospital admissions in 208,437,165 person years

**Figure Legends**

**Figure 1. The spatial variation of zip code level % Public park cover, NDVI (2008), and % Blue space cover in the contiguous U.S.a**

a To aid in visualization, the % Public park cover map was truncated at 44.0%, the NDVI map was truncated at 0.1 and 0.8 and the % Blue space cover map was truncated at 5.6%

**Figure 2. Associations of percent public park cover, NDVI and percent blue space cover with CVD and RSD hospitalization in the full cohort in stratified analyses by sex (male, female), age (65-74, 75-84, 85+ years), Medicaid eligibility (not eligible, eligible), race (White, Black, unknown/other) and region (West, South, Northeast, Midwest).a**

a Associations are expressed per IQR increase of the CVD hospitalization (full) cohort (IQR Percent public park cover: 15·9, NDVI: 0·27, Percent blue space cover: 3·2). Models included public park, NDVI, blue space and were adjusted for calendar year, region, U.S. census covariates, % ever smoked, summer temperature, summer specific humidity and summer total precipitation, an offset for total person-time and strata for all possible combinations of sex, race, Medicaid Eligibility, age at study entry (2-year categories), and follow-up year.

**Figure 3. Associations of percent public park cover, NDVI and percent blue space cover with CVD and RSD hospitalization in the full cohort in stratified analyses by median household income, median home value and percent below the poverty level.a, b**

a Associations are expressed per IQR increase of the CVD hospitalization (full) cohort (IQR Percent public park cover: 15·9, NDVI: 0·27, Percent blue space cover: 3·2). Models included public park, NDVI, blue space and were adjusted for calendar year, region, U.S. census covariates, % ever smoked, summer temperature, summer specific humidity and summer total precipitation, an offset for total person-time and strata for all possible combinations of sex, race, Medicaid Eligibility, age at study entry (2-year categories), and follow-up year.

b To define strata, we used the following quantiles (q33.3, q66.7) for the CVD cohort: median household income ($1,000): 39.9, 55.6; median home value ($1,000): 107.4, 196.3; percent below the poverty level (%): 6.4, 11.4; for the RSD cohort: median household income ($1,000): 40.0, 55.7; median home value ($1,000): 107.7, 196.3; percent below the poverty level (%): 6.4, 11.4.