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Neighbourhood greenness and income of occupants in four German areas: GINIplus and LISApus

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Manuscripts

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4 **Neighbourhood greenness and income of occupants in four German areas:**
5 **GINIplus and LISApus**
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Abstract

Objective: We investigated whether families with lower individual-level socioeconomic status (SES), as defined by income, reside in less green neighbourhoods in four areas in Germany.

Methods: Home address and income data were collected from families participating in two German birth cohorts – GINIplus and LISApplus. Net equivalent household income was categorized into study area-specific tertiles and used as a proxy for individual-level SES. Neighbourhood greenness was calculated in circular 500-m buffers around a home address and defined as: 1) the mean normalized difference vegetation index (NDVI); 2) percent tree cover. Area-specific associations between net equivalent household income and neighbourhood greenness were assessed by linear models corrected for cohort, number of children and area-level SES.

Results: In the urban Munich and Leipzig areas, families in the low income tertile resided in neighbourhoods with lower NDVI compared to those in the high income tertile (mean percent change in NDVI: -3.99 (95% confidence interval = -6.74 to -1.25) and -5.53 (-10.89 to -0.18), respectively). In contrast, in the rural Wesel area, families in the low income tertile resided in neighbourhoods with higher NDVI (2.91 (0.53 to 5.29)) compared to those in the high income tertile. In rural Bad Honnef area, the association was similar to Wesel but not significant. For tree cover, the association was observed only in the urban Munich area, and was in-line with that for NDVI.

Conclusions: This study provides suggestive evidence that the presence and direction of associations between greenness and SES is place-specific in Germany.

What is already known on this subject?

- People with lower individual-level socioeconomic status (SES) often reside in deprived areas with higher environmental pollution and limited access to resources
- Area-level SES was negatively associated with neighbourhood vegetation level in one Australian study, but no study has investigated whether such link exists with individual-level SES

What this paper adds?

- Presence and direction of associations between individual-level SES and neighbourhood greenness is place-specific in Germany
- The observed differential associations appear to be mainly due to rural-urban differences

Introduction

Epidemiological research suggests that residing in a green neighbourhood is beneficial for many health outcomes¹, in particular mental health² and birth weight³. Interestingly, many studies investigating the effects of vegetation level (i.e. greenness) on health report that associations appear strongest among those of low individual-level socioeconomic status (SES)¹. Several hypotheses have been proposed to explain such differences. In particular, people with low individual-level SES are more likely to be less mobile and therefore spend more time close to their residence. Consequently, they are also more likely to be more influenced by their neighbourhood⁴.

Greenness is not equally distributed across space, and neighbourhoods with lower area-level SES may lack vegetation, as was demonstrated by Astell-Burt and colleagues⁵ for five Australian cities. However, to date, no study has examined the possible association between individual-level SES and neighbourhood greenness. Therefore, we investigated whether families with lower individual-level SES reside in less green neighbourhoods in two urban and two rural areas in Germany.

Methods

Data were obtained from parent-completed questionnaires of participants in the 15-year follow-ups of two multicenter German birth cohorts – GINIplus and the LISAplus^{6,7}. Both studies have been approved by local ethics committees and informed consent was obtained from all families. Net equivalent (i.e. per-person) household income (eur/month), which was considered as a proxy of individual-level SES, was categorized into area-specific tertiles and treated as the predictor in our analyses. As the birth cohorts have nearly identical study

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3 designs, data were pooled and are presented by geographical study area – Munich (47.6%
4 families resided in urban surroundings, for details see online supplement, Figure S1 and Table
5 S1), Leipzig (64.7% urban residences), Bad Honnef (5.8% urban residences), and Wesel
6 (1.3% urban residences).
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12 Greenness was defined using two variables, which were calculated in a 500-m circular buffer
13 around the home addresses: 1) the mean normalized difference vegetation index (NDVI); 2)
14 percent tree cover. NDVI (0 to 1, unitless) is a measure for all vegetation and is based on the
15 difference of surface reflectance in two vegetation-informative wavelengths – visible red light
16 and near-infrared light⁸. To calculate NDVI, we used cloud-free Landsat 5 TM satellite
17 images at a resolution of 30 m (Source: <http://earthexplorer.usgs.gov/>), obtained during
18 vegetation rich months in 2003. Tree cover (0 to 100%) data were obtained from Landsat
19 Vegetation Continuous Fields⁹ maps at a resolution of 30 m for 2005 (Source:
20 <http://glcfapp.glcf.umd.edu/data/landsatTreecover/>). Since the distribution of the tree cover
21 data was right-skewed, this variable was normally log-transformed prior to regression
22 analyses. Afterwards, the effect estimates were back-transformed from the log scale.
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38 Area-specific associations between individual-level income and neighbourhood greenness
39 were analyzed using linear models corrected for study (GINIplus observation / GINIplus
40 intervention / LISApplus; applicable for Munich and Wesel areas only), number of children in
41 the household (1 / 2 / 3 / 4 or more / missing) and the German Index of Multiple Deprivation
42 (GIMD) for municipalities (data mainly for 2006)¹⁰, the latter of which acts as a measure for
43 area-level SES. Results are presented as percent change in NDVI and tree cover with
44 corresponding 95% confidence intervals (CIs).
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55 Since Munich and Leipzig families resided in urban as well as rural surroundings, for these
56 areas, we additionally stratified our analyses by urbanization to check for effect modification.
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Results

Data on greenness and individual-level SES were available for 1865 families from Munich, 337 from Leipzig, 155 from Bad Honnef and 1439 from Wesel. On average, families from the urban Munich area had the highest net equivalent household incomes while those in rural Wesel had the lowest incomes. Families from the two urban areas – Munich and Leipzig - lived in neighbourhoods with lower average levels of NDVI and tree cover compared to the rural areas – Bad Honnef and Wesel (see online supplement, Table S1). NDVI and tree cover were positively correlated in Munich and Bad Honnef (Spearman correlation coefficients (ρ) for both areas=0.63) but not in Leipzig and Wesel (ρ =not significant and ρ =-0.09, respectively). Families from the East German Leipzig area resided in the most deprived municipalities, as defined by the GIMD.

In both crude and adjusted models, net equivalent household income and greenness were differentially associated across areas (see Figure 1 and online supplement, Table S2). In the urban Munich and Leipzig areas, families in the low income tertile resided in neighbourhoods with lower NDVI compared to those in the high income tertile (percent change: -3.99 (95% CI=-6.74 to -1.25) and -5.53 (-10.89 to -0.18), respectively). When stratified by urbanization, in Leipzig, this association was stronger in urban dwellers (-7.40 (-13.94 to -0.86) and -10.78 (-17.76 to -3.80), for low and medium income tertiles vs. high tertile, respectively), and null in rural dwellers. In the Munich area, no such difference between urban and rural dwellers was observed.

In contrast, in the rural Wesel area, families in the low income tertile resided in neighbourhoods with higher NDVI (2.91 (0.53 to 5.29)). In the rural Bad Honnef area, the association was similar to that in Wesel but not significant.

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3 Regarding the other greenness metric - tree cover, - the association with income was apparent
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5 only in the Munich area and in-line with that for NDVI.
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9 Moreover, in two of four areas, neighbourhood greenness was associated with area-level SES,
10 as defined by the GIMD, independently from individual-level SES. In the Munich area,
11 greener neighbourhoods were located in less deprived municipalities (percent change per 1
12 unit increase in GIMD: -1.57 (95% CI=-1.84 to -1.27) for NDVI and -3.79 (-5.41 to -2.15) for
13 tree cover). In the Wesel area, the association for NDVI was in the same direction (-0.59 (-
14 0.78 to -0.40) while for tree cover the tendency was opposite (2.61 (2.02 to 3.20)).
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26 **Discussion**

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29 Lower individual-level SES, as defined by net equivalent household income, was associated
30 with less vegetation in a neighbourhood, as defined by NDVI, in the urban Munich and
31 Leipzig areas. An opposite trend was observed in the rural Wesel area and Bad Honnef area.
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33 Tree cover was only positively associated with individual-level SES in the Munich area.
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39 In urban settings with limited natural space, greener neighbourhoods are a valuable resource
40 and they drive up the price of surrounding apartments¹¹. These neighbourhoods may become
41 unaffordable for families with lower income. Therefore, it is not entirely surprising that in our
42 two urban areas, families with higher income resided in greener neighbourhoods. In two rural
43 areas, however, the association was reversed. It is possible that in rural communities, better
44 infrastructure (e.g. proximity to transport arteries or shopping facilities) plays a more decisive
45 role than access to greenness when choosing a place of residence.
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56 Such rural-urban differences are in-line with the findings from studies on unequal exposure to
57 air pollution, which have demonstrated that urban dwellers from higher individual-level SES
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3 groups reside in less polluted places while this tendency is reversed or not apparent among
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5 rural dwellers¹². This suggests that the presence and direction of an association between
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7 greenness and individual-level SES could differ depending, in particular, on urbanization
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9 level. The latter is supported by the main results of this study and by the fact that the positive
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11 association between individual-level income and NDVI was only apparent among urban
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13 dwellers in Leipzig. Nevertheless, observed place-specific associations with area-level SES
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15 could not be explained by the degree of urbanization.
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19 Caution is however always needed when interpreting findings with the NDVI, as its meaning
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21 may differ by area. In some areas, vegetation is largely composed of trees (Munich and Bad
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23 Honnef) while in others, it is composed of herbaceous vegetation (Leipzig and Wesel). This
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25 may explain why associations for NDVI differ from those for tree cover in this study, with
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27 both individual- and area-level SES. Nevertheless, it remains remarkable that inequality in
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29 exposure to greenness could be identified in a rich country like Germany, where differences
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31 between individual- as well as area-level socioeconomic deprivation may be smaller than in
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33 other developed countries.
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38 The inclusion of four study areas that differed substantially in their degree of urbanization and
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40 area-level deprivation, and the standardized objective assessment of the greenness variables
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42 are important strengths of the current study. However, limitations include the fact that the
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44 GINIplus and LISApplus birth cohorts were not specifically designed to assess the studied
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46 associations and that the sample size in Bad Honnef might not have been large enough to
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48 detect statistically significant associations. Moreover, net equivalent household income may
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50 not be an optimal measure of individual-level SES, as the latter should ideally include some
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52 information on education and occupation. Finally, the generalizability of our findings is
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54 limited as only German-speaking families were recruited and families with low individual-
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level SES were less likely to be initially recruited into the birth cohorts and to participate in the 15-year follow-up.

Confidential: For Review Only

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Conflicts of interests

All co-authors have no conflicts of interest.

Figure legend

Figure 1 Associations between individual-level socioeconomic status (SES), as defined by net equivalent household income, and neighbourhood greenness. Models adjusted for study (applicable for Munich and Wesel areas only), number of children in the household and the German Index of Multiple Deprivation, as a measure for area-level SES. Results are presented as percent change in NDVI and tree cover with corresponding 95% confidence intervals.

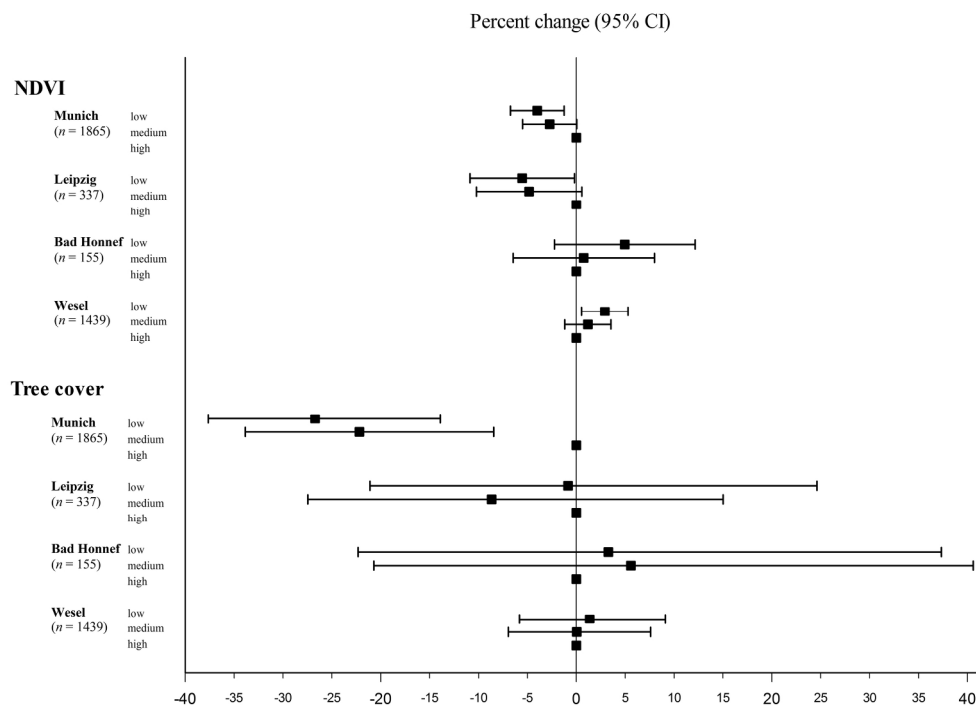


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204x147mm (300 x 300 DPI)

ONLINE SUPPLEMENT

**Neighbourhood greenness and income of occupants in four German areas:
GINIplus and LISApus**

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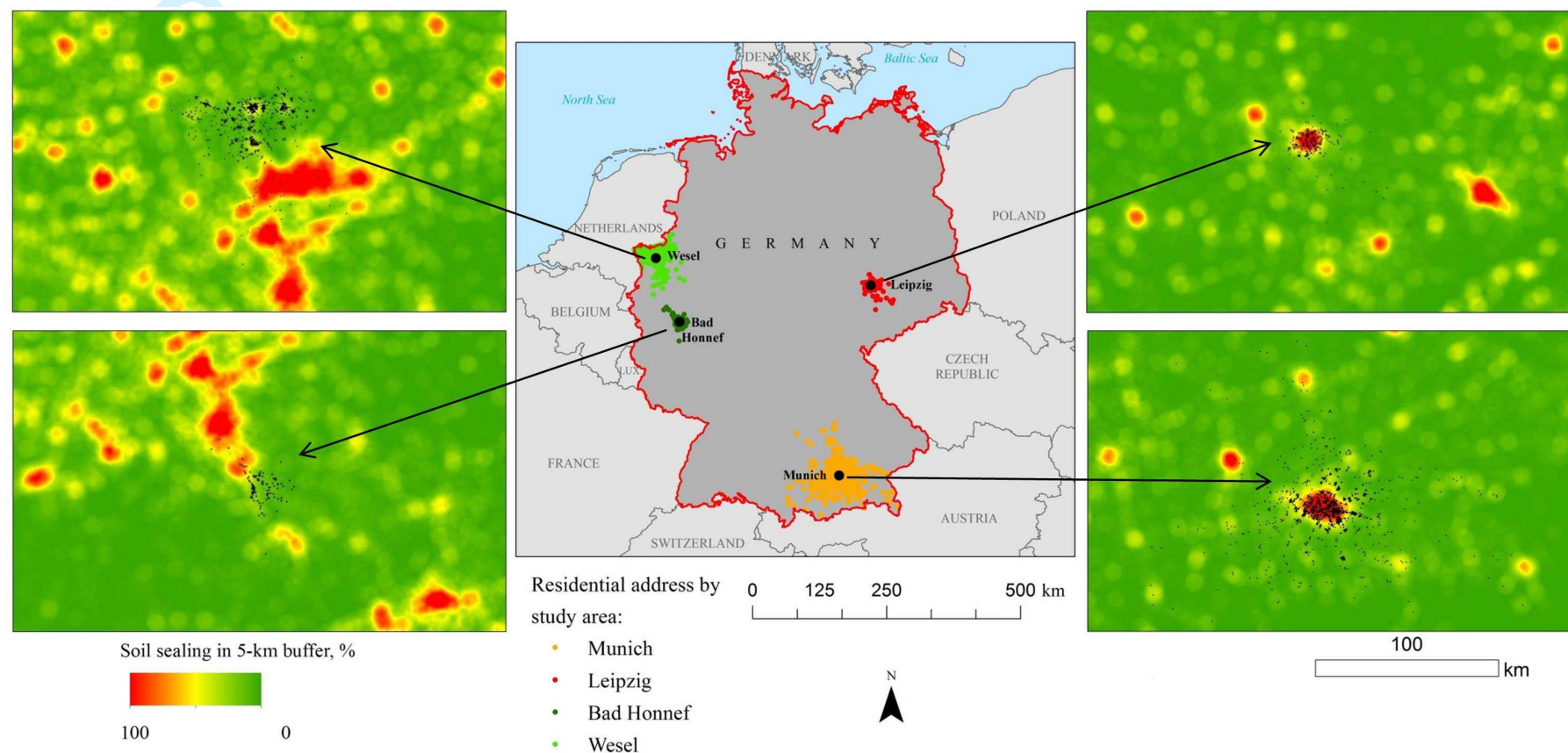
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34 **Figure S1** Map of Germany with plotted residences of study participants, highlighted by study area, together with zoomed in maps with underlying
 35 urbanization degree. Urbanization degree map is based on percent sealed soil in 5-km buffer (0% (green) to 100% (red)). The map was created
 36 based on a raster dataset with a spatial resolution of 100 m for 2006, freely available from the European Environment Agency (Source:
 37 [http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing#tab-additional-](http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing#tab-additional-information)
 38 [information](http://www.eea.europa.eu/data-and-maps/data/eea-fast-track-service-precursor-on-land-monitoring-degree-of-soil-sealing#tab-additional-information)). Residences at places with <25% soil sealed were classified as rural and those with $\geq 25\%$ soiled sealed as urban.
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Table S1 Description of study population

Variable / Study area	Munich (n=1865)	Leipzig (n=337)	Bad Honnef (n=155)	Wesel (n=1439)
Study ¹				
GINIplus observation	614 (32.9)	NA	NA	809 (56.2)
GINIplus intervention	554 (29.7)	NA	NA	490 (34.1)
LISAplus	697 (37.4)	337 (100.0)	155 (100.0)	140 (9.7)
Number of children in the household ¹				
1	610 (32.7)	146 (43.3)	56 (36.1)	454 (31.6)
2	890 (47.7)	142 (42.1)	72 (46.5)	676 (47.0)
3	247 (13.2)	31 (9.2)	20 (12.9)	226 (15.7)
4 and more	52 (2.8)	7 (2.1)	3 (1.9)	43 (3.0)
missing	66 (3.5)	11 (3.3)	4 (2.6)	43 (3.0)
GIMD ^{2 4}	10.3±3.9	22.9±3.8	14.9±4.2	15.8±5.2
Urban dwellers ^{1 5}	888 (47.6)	218 (64.7)	9 (5.8)	19 (1.3)
Net equivalent household income (eur/month) ^{2 6}	1986.8±787.3	1686.5±803.4	1673.5±735.0	1361.1±631.8
low ⁷	133 - 1548	265 - 1250	298 - 1300	167 - 1058
medium ⁷	1552 - 2250	1300 - 1806	1310 - 1800	1071 - 1452
high ⁷	2280 - 5128	1833 - 5128	1875 - 4167	1500 - 5128
NDVI ^{2 8}	0.35±0.09	0.29±0.06	0.46±0.09	0.43±0.08
Tree cover (%) ³	1.2±4.4	2.0±2.4	9.6±2.1	6.3±1.8

1 – n (%)

2 – Mean ± standard deviation

3 – Geometric mean ± geometric standard deviation

4 – German Index of Multiple Deprivation, higher value means greater level of deprivation of the municipality where the family resides - measure for area-level SES

5 – Classification into urban or rural is based on percent sealed soil in 5-km buffer.

Residences at places with <25% soil sealed were classified as rural, ≥25% as urban.

6 – Categorized into study area-specific tertiles

7 – Range (minimum – maximum)

8 – Normalized Difference Vegetation Index

Table S2 Associations between individual-level socioeconomic status (SES), as defined by net equivalent household income, and neighbourhood greenness. Results are presented as percent change in NDVI and tree cover with corresponding 95% confidence intervals.

Study area	Greenness variable	Net household income ¹	Crude model	Adjusted model ²
Munich (n=1865)	NDVI	low	-4.7 (-7.5 to -1.9)	-4.0 (-6.7 to -1.2)
		medium	-3.3 (-6.2 to -0.5)	-2.7 (-5.5 to 0.0)
		high	ref.	ref.
	Tree cover	low	-27.7 (-38.6 to -15.0)	-26.7 (-37.6 to -13.9)
		medium	-23.1 (-34.7 to -9.5)	-22.2 (-33.9 to -8.4)
		high	ref.	ref.
Leipzig (n=337)	NDVI	low	-5.9 (-11.2 to -0.6)	-5.5 (-10.9 to -0.2)
		medium	-4.9 (-10.3 to 0.5)	-4.8 (-10.2 to 0.6)
		high	ref.	ref.
	Tree cover	low	-0.1 (-20.4 to 25.3)	-0.8 (-21.1 to 24.6)
		medium	-8.2 (-27.1 to 15.6)	-8.7 (-27.5 to 15.0)
		high	ref.	ref.
Bad Honnef (n=155)	NDVI	low	5.3 (-2.1 to 12.7)	5.0 (-2.2 to 12.1)
		medium	-0.1 (-7.5 to 7.3)	0.8 (-6.5 to 8.0)
		high	ref.	ref.
	Tree cover	low	4.3 (-21.8 to 39.2)	3.3 (-22.3 to 37.3)
		medium	6.2 (-20.5 to 41.9)	5.6 (-20.7 to 40.6)
		high	ref.	ref.
Wesel (n=1439)	NDVI	low	3.8 (1.4 to 6.2)	2.9 (0.5 to 5.3)
		medium	1.4 (-0.9 to 3.8)	1.1 (-1.2 to 3.5)
		high	ref.	ref.
	Tree cover	low	-2.7 (-9.7 to 4.8)	1.4 (-5.8 to 9.1)
		medium	-1.7 (-8.8 to 5.9)	0.1 (-7.0 to 7.6)
		high	ref.	ref.

1 – Categorized into study area-specific tertiles

2 - Models adjusted for study (applicable for Munich and Wesel areas only), number of children in the household and the German Index of Multiple Deprivation, as a measure for area-level SES.