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Does nature make us less lonely? Analysis in Bulgaria's five largest cities

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ABSTRACT

Background: Loneliness is prevalent and increases risks of disease and premature death. We aimed to investigate whether greater exposure to nature is associated with less loneliness in urban Bulgarian adults, and whether the association was modified by sociodemographic factors.
Methods: The analytic sample comprised 3604 adults from a cross-sectional population-based survey conducted in 2023 in the five largest Bulgarian cities. Loneliness was self-reported with a single item on a seven-point Likert scale. Availability of nature was assessed by several GIS-derived indicators: normalised difference vegetation index (NDVI), tree cover density, urban green space, all in a 300 m buffer around home, and distance to blue space. Self-reported nature indicators included domestic garden, green space and blue space quality, green space and blue space window view, and time spent in green and blue space. Adjusted negative binomial regressions with random intercept for city district were used to assess associations with loneliness. We further checked effect modification by city type, sex, age, relationship, employment status and education.
Results: Residing in areas with more urban green space, higher green space quality, and green space window view and spending more time in green and blue space were associated with lower loneliness scores. Living in low or high compared to medium level NDVI settings or in areas with higher tree cover density was associated with higher loneliness scores. Sociodemographic factors modified some of these associations.
Conclusions: Our findings underscore the importance of extending and improving structured urban green spaces in Bulgarian cities.

1. Introduction

Even though the world's population has passed the 8 billion mark (Worldometer, 2024), our planet is a lonely place. A systematic review with meta-analysis has estimated that worldwide one in five older adults experiences chronic loneliness (Hajek et al., 2024). A non-probabilistic online survey with 22,873 respondents from the European Union (EU) found that 13 % of adults over 16 suffer from chronic loneliness and that the prevalence of temporary loneliness is even higher with 35 % (The EU Loneliness Survey, 2024).

That loneliness and depression are interrelated seems obvious and, indeed, was confirmed by a meta-analysis (Erzen and Çikrikci, 2018). A

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growing body of research demonstrates that loneliness is associated with a number of adverse health outcomes besides depression (Erzen and Çikrikci, 2018), as well as a shorter lifespan (Donovan and Blazer, 2020). In particular, a meta-analytic review estimated that loneliness is related to 26 % higher odds of premature all-cause mortality (Holt-Lunstad et al., 2015). According to another systematic review and meta-analysis based on prospective studies in middle-aged and older adults, loneliness increases the risk of incident cardiovascular diseases (CVDs) by 16 % (Albasheer et al., 2024). Loneliness has also been shown to elevate the risk of dementia by 61 % (Oken et al., 2024). Even though the empirical evidence for a rise of loneliness over time is still insufficient (Luhmann et al., 2023), loneliness has been recognised as a public health concern in the USA (Cacioppo and Cacioppo, 2018) and has even been labelled an epidemic (Murthy, 2017). Recently, the World Health Organization has created The Commission on Social Connection, which is a sign of recognition of loneliness as a global health problem (World Health Organization, 2023).

Loneliness should not be mixed up with the related concepts of social isolation or being alone (Victor and Smith, 2019). While social isolation is a lack of social contacts and is objectively measurable, loneliness is the subjective feeling of being socially deprived, disconnected, and not supported by others (Donovan and Blazer, 2020). Although loneliness is not a disease itself, it is already being medicated (McLennan and Ulijaszek, 2018). Existing interventions to reduce the condition are weak to unsuccessful (Akhter-Khan and Au, 2020).

Instead of looking at loneliness as a medical problem, Feng and Astell-Burt propose a different angle: they posit that loneliness is a consequence of increased urbanisation, disconnection from nature, and transforming societal relations (Feng and Astell-Burt, 2022). "Loneligenic environments", as the authors christened them, are thought to cause or worsen loneliness because they lack places where people can relax, socialise, or do sports (Astell-Burt et al., 2023). Urban nature, and green spaces in particular, are among such vital places, and their potential protective role in reducing loneliness has already been explored and mainly confirmed, as is summarised by a recent systematic review of 22 observational and interventional studies (Astell-Burt et al., 2022b) and further confirmed by more recent studies (Astell-Burt et al., 2023; Astell-Burt et al., 2024a; Astell-Burt et al., 2024b; Villeneuve et al., 2024; Wang et al., 2024). Three parallel randomized controlled trials in Spain, Czech Republic, and Finland to probe the effectiveness of nature-based in combination with group-based interventions to reduce loneliness are ongoing in the RECETAS project (Coll-Planas et al., 2024). The theoretical underpinnings for such studies are provided by ideas from environmental psychology such as relational restoration theory (RRT, Hartig, 2021) and collective restoration theory (CRT, Hartig, 2021). RRT and CRT extend the individual-centric attention restoration theory (Kaplan and Kaplan, 1989) and stress reduction theory (Ulrich, 1983) by acknowledging that transactions between individuals can take place in and be shaped by natural environments. RRT focuses on how nature restores and creates relational resources in close relationships. CRT further widens the scope and looks at how nature can promote positive interactions in local communities.

One shortcoming of the existing research on nature and loneliness is that the majority of studies were conducted in high-income countries; none came from Eastern Europe. Only a few previous research efforts considered more than one type of exposure to nature (Astell-Burt et al., 2023; Wang et al., 2024). Finally, only a handful of studies investigated whether the relationship between nature and loneliness could differ across various population strata (Astell-Burt et al., 2022a, 2023; Wang et al., 2024). In our study, we aimed to address those gaps and to investigate whether greater exposure to nature is associated with less loneliness in the southeastern European country of Bulgaria, where the prevalence of chronic loneliness is among the highest in the EU (The EU Loneliness Survey, 2024). We employed several indicators of exposure to nature based on geospatial data, as well as people's perceptions of availability, quality, and use of nature collected in an interview. Together these indicators capture many related yet distinct aspects of exposure to nature and help draw a more comprehensive picture. In addition, we checked effect modification of the associations of interest by city type, sex, age, relationship and employment statuses, and education.

2. Methods

2.1. Study population

We utilised data from an omnibus cross-sectional population-based study on environmental characteristics, their perception, and health in adults from the five largest cities of Bulgaria – Sofia, Plovdiv, Varna, Burgas, and Ruse (Helbich et al., 2024; Dzhambov et al., 2025). Sofia, Plovdiv, and Ruse are landlocked cities, while Varna and Burgas are seaside cities. In brief, stratified random sampling was used to recruit participants from eight spatial typologies that were defined by residential environmental factors, specifically, traffic-related air pollution and noise ($\geq/<$ 50 m distance to a major road), air pollution from domestic heating or cooking ($\geq/<$ 100 m distance to $\geq$ 10 households using fossil fuel for heating), and green space ($\geq/<$ 300 m to a green urban area) in line with a previous study in Sofia (Dzhambov et al., 2023). A quota sampling approach was applied to obtain a sample that is representative for each city in terms of age, sex, education, and ethnicity. Fieldworkers from a professional survey company recruited the participants between August and October 2023 after receiving training from our research team. Participants were interviewed at their homes in person and answers were marked on tablets. To be included in the study, participants had to be at least 18 years old, fluent in Bulgarian, and to have lived in their current home for at least one year. In total, 4640 respondents were recruited: 1512 from Sofia, 1012 from Plovdiv, 1001 from Varna, 655 from Burgas, and 460 from Ruse, which was roughly proportional to the population size of each city. Response rates were moderate: 30.55 % in Sofia, 58.40 % in Plovdiv, 45.56 % in Varna, 53.73 % in Burgas, and 56.37 % in Ruse. After listwise deletion of missing data and of participants who had lived at their current home for less than a year, our analytic sample comprised 3604 participants (Fig. S1).

The Ethics Committee at the Medical University of Plovdiv approved the study protocol (Protocol № 4/04.05.2023, Opinion № P-1253/17.05.2023). Participants' verbal informed consent to participate in the survey and their consent to personal data processing was obtained and marked on a tablet device before the interview could start. We strictly adhered to the EU data protection laws. No monetary or other incentives were offered. This article is prepared according to the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement (von Elm et al., 2007).

2.2. Loneliness assessment

Loneliness was assessed with a single item, in line with Astell-Burt et al. (2022a): 'Thinking of the last two weeks, how much do you agree with the statement "I felt lonely"?' Responses were collected on a seven-point Likert scale (0 = strongly disagree, 1 = disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = agree, 6 = strongly agree).

2.3. Exposure to nature

2.3.1. GIS-derived indicators

Fieldworkers geocoded the home addresses using global positioning system (GPS) devices. The spatial accuracy of the address coordinates was evaluated based on auxiliary data, such as from a cadaster, and, if needed, manually corrected on a case-by-case basis using a geographic information system (GIS). Geographic data processing was conducted in QGIS 3.28.2 and ArcGIS Pro 2.5.1.

Availability of nature was assessed by several GIS-derived indicators: normalised difference vegetation index (NDVI), tree cover density, percent of urban green space, all computed in a concentric 300 m buffer around home, and distance to blue space in metres. The buffer radius of 300 m corresponds to the World Health Organisation (WHO) guidelines (Annerstedt van den Bosch et al., 2016).

NDVI (Tucker, 1979) measures the degree of vegetation and exploits that plants absorb visible red light for photosynthesis and reflect near-infrared light to prevent overheating. NDVI is defined as (NIR − Red)/(NIR + Red), where Red and NIR are the measured fractions of spectral reflectance in the red and near-infrared wavelength ranges, respectively. Since NIR and Red range from 0 to 1, NDVI values range from −1 to +1, with values close to +1 indicating densely vegetated area and values close to −1 indicating water. NDVI was calculated using Sentinel-2 satellite images with a 10 m spatial resolution from the EU's Copernicus programme (European Union, Copernicus Land Monitoring Service, 2024). We used images taken between May and September 2022 to obtain maximum exposure contrasts. Tree cover density was measured in percent and assigned based on the 2018 Copernicus Tree Cover Density grid with a 10 m spatial resolution derived from Sentinel-2 satellite images (European Union, Copernicus Land Monitoring Service, 2020b).

Urban green space in percent and Euclidean distance to the nearest blue space in metres are based on the European Urban Atlas land use/land cover (LU/LC) data for 2018 with a minimum mapping unit of 0.25 ha (European Union, Copernicus Land Monitoring Service, 2021). We defined urban green space as LU/LC class '14100' (= 'green urban areas') and blue space as class '50000' (= 'water').

2.3.2. Self-reported indicators

Information on several self-reported indicators identifying nature perception and use was collected during the interview. These included presence of a domestic garden, green space and blue space quality, green space and blue space window view, time spent in green space, and time spent in blue space.

Information on the presence of a domestic garden was collected via the question "Does your home have a yard or garden with vegetation where you can spend time?"

Neighbourhood green and blue space quality were assessed by the following two items: "The green spaces in my neighbourhood are of high quality (e.g., they are well-maintained, beautiful, peaceful, lack litter)" and "The blue spaces in my neighbourhood are of high quality (e.g., they are well-maintained, have clear water, smell good, lack litter)." Perceived green and blue space window views were assessed by the following two items: "When I am home, I can see a lot of green vegetation/blue spaces from my windows." Responses were collected on five-point Likert scales (1 = completely disagree, 2 = mostly disagree, 3 = neither agree nor disagree, 4 = mostly agree, 5 = completely agree).

Time spent in green space and blue space in minutes per week was collected through two items: "During a typical week recently, how much overall time per week do you spend in green spaces (e.g., in the park, in nature)/near or in bodies of water (e.g., river, beach, lake)?"

2.4. Statistical analysis

As descriptive statistics of the analytic sample we chose arithmetic means and standard deviations for numerical variables and frequencies and percentages for categorical variables. We used boxplots to detect outliers in numerical variables and found none. Pearson correlations were utilised to check directions and strengths of bivariate associations between numerical variables.

Since the loneliness variable can be modelled as count data and showed overdispersion, negative binomial regressions were used. The estimated intraclass correlation coefficients (ICC) for a grouping of loneliness values by city (ICC = 0.03) and by city district (ICC = 0.24) suggested that loneliness values were not correlated within the five cities but somewhat correlated within the 173 city districts. ICC values were estimated under the repeatability setting of the icc_counts function from the iccCounts package version 1.1.2 in R version 4.4.0 (R Core Team, 2024). To account for study participants from the same city district having more similar loneliness scores due to city-district-specific factors besides the exposures of interest, we used mixed-effects models with a random intercept for city district. Models were fitted using the glmmTMB function from R's glmmTMB package version 1.1.10. Both the ICC computation and the mixed negative binomial regressions assumed that loneliness values followed a negative binomial probability density function with variance increasing linearly with the mean. Individual models were fitted to assess the associations of loneliness with each GIS-derived (i.e., NDVI, tree cover density, percentage of urban green space, and distance to blue space) and self-reported (i.e., garden, green space quality, blue space quality, green space window view, blue space window view, time spent in green space, and time spent in blue space) indicator of exposure to nature. After reviewing the literature for determinants of loneliness, we constructed a directed acyclic graph (DAG; Greenland et al., 1999; Fig. S2) to identify the minimum sufficient adjustment set. As a result, each of our eleven main models was adjusted for sex, age in full years, highest attained education (primary or lower vs. secondary vs. higher), and difficulty to survive with the monthly household income (difficult vs. somewhat difficult vs. easy). The latter two variables were used as proxies of socioeconomic status (SES). We also adjusted the models for city to reflect the stratified sampling of the study design.

Visual inspection of the fitted curves from generalised additive models (GAMs; Hastie and Tibshirani, 1986), that used the same adjustment set as the main models, identified a U-shaped relationship between NDVI and loneliness. To capture this functional shape while still obtaining effect estimates that are easy to interpret and plot, we first split the continuous NDVI variable into quartiles and then constructed a categorical NDVI variable with three levels, where the lowest (Q1) and highest (Q4) NDVI quartiles are compared to the two middle quartiles (Q2 combined with Q3) that serve as the reference category. The NDVI ranges for the three categories are defined in Table S1. The other continuous exposure variables showed approximately linear relationships with loneliness and were left as-is. The residual diagnostics of the regression models were produced using R's DHARMa package (Hartig, 2022) and confirmed that the regression models fit the data well.

To check the consistency of the results, we ran several sensitivity analyses: (1) models adjusted only for city, (2) main models additionally adjusted for all covariates that relate either to outcome or exposures: employment status (student/employed vs. unemployed/retired/on maternity leave), relationship status (widowed vs. single/divorced vs. married/in relationship), and urbanicity measured by average imperviousness density in percent in 1000 m buffers around home assigned based on Copernicus data from 2018 (European Union, Copernicus Land Monitoring Service 2020a), (3) models as in (2) but additionally adjusted for the percentage of people in the same cadastral map polygon (of which there were 17,619 in the five cities) with higher education and the percentage of people in the same cadastral map polygon that were employed, both provided by the National Statistical Institute of Bulgaria (2023) based on the 2021 census, (4) models for NDVI, tree cover density, and urban green space calculated in buffers with radius 500 m and 1000 m, (5) models fitted to a subsample after excluding 180 participants with limited mobility defined as a physical disability that had prevented them from going outside on their own during the last two weeks, and (6) models fitted to a subsample after excluding 142 participants with non-Bulgarian, mainly of Roma, Turk, and Armenian ethnicity who might differ from ethnic Bulgarians in their environmental preferences and practices as observed for other ethnic minorities elsewhere (Markevych et al., 2017; Dadvand et al., 2014). We concluded on the presence of an association based on consistent directionality across the model variants from main and sensitivity analyses instead of focusing on an arbitrary threshold of statistical significance as

recommended by the American Statistical Association (Wasserstein and Lazar, 2016; Wasserstein et al., 2019). In practical terms, this means that for every exposure we looked through the plotted effect estimates and identified those associations with loneliness whose 95 % confidence intervals (CIs) had at least three quarters of their width on the positive or negative side of the no-effect reference line (located at 1 for the count ratios produced by negative binomial regression).

We also conducted analyses stratified by the following factors which were suspected to modify the associations of interest: (1) city type (landlocked: Sofia, Plovdiv, Ruse vs. seaside: Varna, Burgas), (2) sex, (3) age ($\leq$ 30 years vs. 31 to 65 years vs. $>$ 65 years), (4) relationship status (widowed vs. single/divorced vs. married/in relationship), (5) employment status (student/employed vs. unemployed/retired/on maternity leave), and (6) education (primary/lower vs. secondary vs. higher). In seaside cities coastal areas are most attractive. There is also evidence that in seaside cities higher exposure to blue space, but not green space, is positively associated with mental health (e.g., Nutsford et al., 2016). This led us to expect that the association of blue space with loneliness would be stronger in seaside than in landlocked cities. We also expected subgroups who tend to be fitter and more physically active to benefit more from natural spaces in their neighbourhood (males vs. females, younger vs. older people, which includes most widowed people) (Garrett et al., 2020). We expected employed people, who have less time but more need for relaxation from their stressful lives, to profit more from nearby natural spaces than unemployed people. We assumed people with lower education to be less mobile and of worse health than people with higher education and, therefore, to be more dependent on nearby natural spaces and to show greater health improvements (Markevych et al., 2017). Little to no overlap of 95 % CIs across strata was considered an indication of effect modification.

3. Results

3.1. Descriptive characteristics of the analytic sample

Study participants had a mean age of 50.5 years and 50.9 % were female (Table 1). The majority of participants had completed a secondary education (56.8 %). Around one-fifth (20.4 %) reported that it was difficult for them to survive on their monthly household income. About two-thirds (63.4 %) of participants were in a relationship.

About 4.5 % of study participants in the analytic sample agreed or strongly agreed with feeling lonely during the last two weeks (Table 1). When also including participants who somewhat agreed, this percentage rose to 11.5 %. Supplementary Figs. S3–S6 show the distribution of loneliness scores stratified by sociodemographic factors. Older participants, participants with primary or lower education, and participants with lower perceived income reported higher loneliness.

On average, study participants lived 2336.8 m away from a blue space and had 7.1 % tree cover density and 5.5 % of urban green space within the 300 m buffer around their homes. Almost one-third (29.2 %) had a domestic garden. The average times spent in green space and blue space were 463.0 and 140.7 min per week, respectively. Descriptive characteristics of GIS-derived and self-reported nature exposures are reported in Table 1. Except for a somewhat smaller proportion of participants with lower perceived income, our analytic sample was comparable with the full original population-representative sample (Table S2).

Table 1
Descriptive characteristics of the analytic sample (n = 3604).

Characteristic	N (%)[a] or mean ± SD[b]
Feeling lonely during last 2 weeks (unitless, 0 to 6)[b]	1.1 ± 1.6
Strongly disagree[a]	1896 (52.6)
Disagree[a]	624 (17.3)
Somewhat disagree[a]	392 (10.9)
Neither agree nor disagree[a]	277 (7.7)
Somewhat agree[a]	252 (7.0)
Agree[a]	102 (2.8)
Strongly agree[a]	61 (1.7)
City[a]	
Sofia	1091 (30.3)
Plovdiv	700 (19.4)
Varna	955 (26.5)
Burgas	460 (12.8)
Ruse	398 (11.0)
Sex – Female[a]	1967 (54.6)
Age (years)[b]	50.5 ± 17.4
Ethnicity[a]	
Bulgarian	3462 (96.1)
Other	142 (3.9)
Education[a]	
Primary or lower	170 (4.7)
Secondary	2046 (56.8)
Higher	1388 (38.5)
Difficulty to survive with the monthly household income[a]	
Difficult	734 (20.4)
Somewhat difficult	1570 (43.6)
Easy	1300 (36.1)
Employment status[a]	
Student/employed	2489 (69.1)
Unemployed/retired/on maternity leave	1115 (30.9)
Relationship status[a]	
Married/in relationship	2285 (63.4)
Single/divorced	892 (24.8)
Widowed	427 (11.8)
Limited mobility - Yes[a]	180 (5.0)
Percentage of people in the same cadastral map polygon with higher education (%)[b]	36.4 ± 13.1
Percentage of people in the same cadastral map polygon who are employed (%)[b]	48.6 ± 6.6
Urbanicity (%)[b]	50.1 ± 14.7
Tree cover density 300 m (%)[b]	7.1 ± 6.0
Tree cover density 500 m (%)[b]	7.6 ± 5.9
Tree cover density 1000 m (%)[b]	8.7 ± 6.0
Urban green space 300 m (%)[b]	5.5 ± 7.8
Urban green space 500 m (%)[b]	6.4 ± 7.3
Urban green space 1000 m (%)[b]	6.7 ± 6.0
Distance to blue space (m)[b]	2336.8 ± 1757.2
Domestic garden - Yes[a]	1052 (29.2)
Green space quality (unitless, 1 to 5)[b]	3.0 ± 1.3
Blue space quality (unitless, 1 to 5)[b]	1.5 ± 1.1
Green space window view (unitless, 1 to 5)[b]	3.6 ± 1.3
Blue space window view (unitless, 1 to 5)[b]	1.4 ± 1.1
Time spent in green space (min/week)[b]	463.0 ± 511.9
Time spent in blue space (min/week)[b]	140.7 ± 294.5

[a] Last column contains count and percentage.
[b] Last column contains mean and standard deviation (SD).

3.2. Associations between nature and loneliness

Participants residing in homes surrounded by low or high levels of NDVI reported higher loneliness scores compared to those with medium NDVI levels (Fig. 1). A higher tree cover density around home was associated with higher loneliness scores. A higher proportion of urban green space around home was related to less loneliness. There was no association with distance to the nearest blue space. The association of tree cover density was replicated in all sensitivity analyses: in crude models (Fig. S7), in overadjusted models (Fig. S9), in overadjusted models additionally adjusted for area-level SES (Fig. S11), when using larger buffer sizes (Fig. S13), when excluding participants with limited mobility (Fig. S14), and when reducing the sample to ethnic Bulgarians (Fig. S16). The associations with NDVI disappeared when using 1000 m buffers. The association with urban green space was not present when using 500 m buffers.

Considering self-reported exposures to nature, green space quality, green space window view, time spent in green space, and time spent in blue space were associated with lower loneliness scores (Fig. 2). These associations were replicated in all sensitivity analyses (Figs. S8, S10, S12, S15, S17). There were some associations with garden and blue

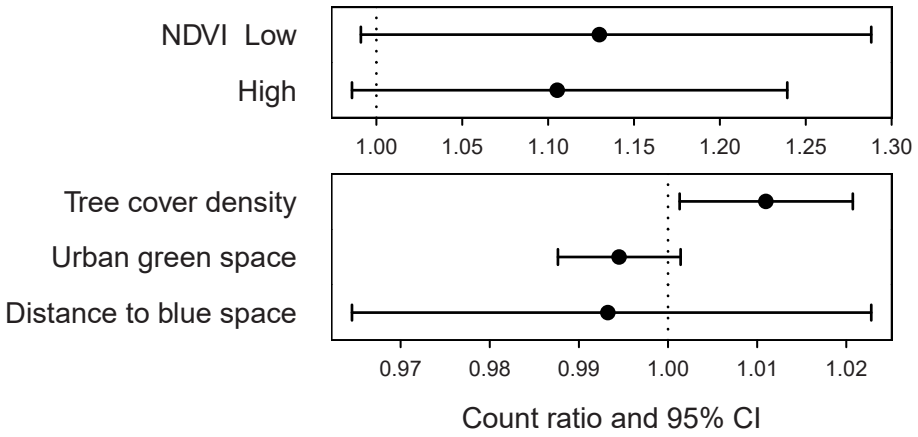


Fig. 1. Associations between **GIS-derived** nature indicators and loneliness, assessed by negative binomial mixed-effects regressions. In the upper pane, effect estimates for low (Q1) and high (Q4) NDVI levels are shown with Q2+Q3 being the reference category in both cases. In the lower pane, the effect estimates are scaled per 10 % for tree cover density and urban green space and per 500 m for distance to blue space. Models are adjusted for city, sex, age, education, and income and have a random intercept for city district.
CI – confidence interval; NDVI – normalised difference vegetation index; Q – quartile.

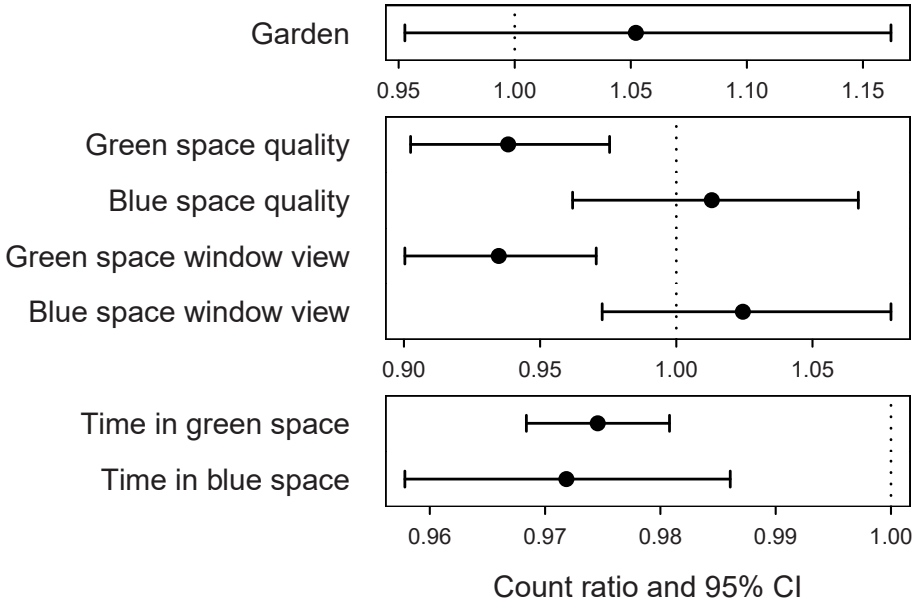


Fig. 2. Associations between **self-reported** nature indicators and loneliness, assessed by negative binomial mixed-effects regressions. The upper pane shows the effect estimate for presence of a domestic garden. The middle pane shows effect estimates scaled per 1 point on five-point Likert scales. In the lower pane, effect estimates are scaled per 60 min/week. Models are adjusted for city, sex, age, education, and income and have a random intercept for city district.
CI – confidence interval.

space window view, but these were not consistent. Table 2 illustrates the consistency of associations across sensitivity analyses. All numerical estimates can be found in Supplement 2.

3.3. *Effect modification of the nature-loneliness associations*

No effect modification by city type (landlocked vs. seaside) was observed across GIS-derived or self-reported nature exposures (Figs. S18 and S19), except that presence of a domestic garden was associated with lower loneliness scores among inhabitants of landlocked cities and with substantially higher loneliness scores in seaside cities (Fig. S19).

There was no indication of any effect modification of the associations by sex (Figs. S20 and S21).

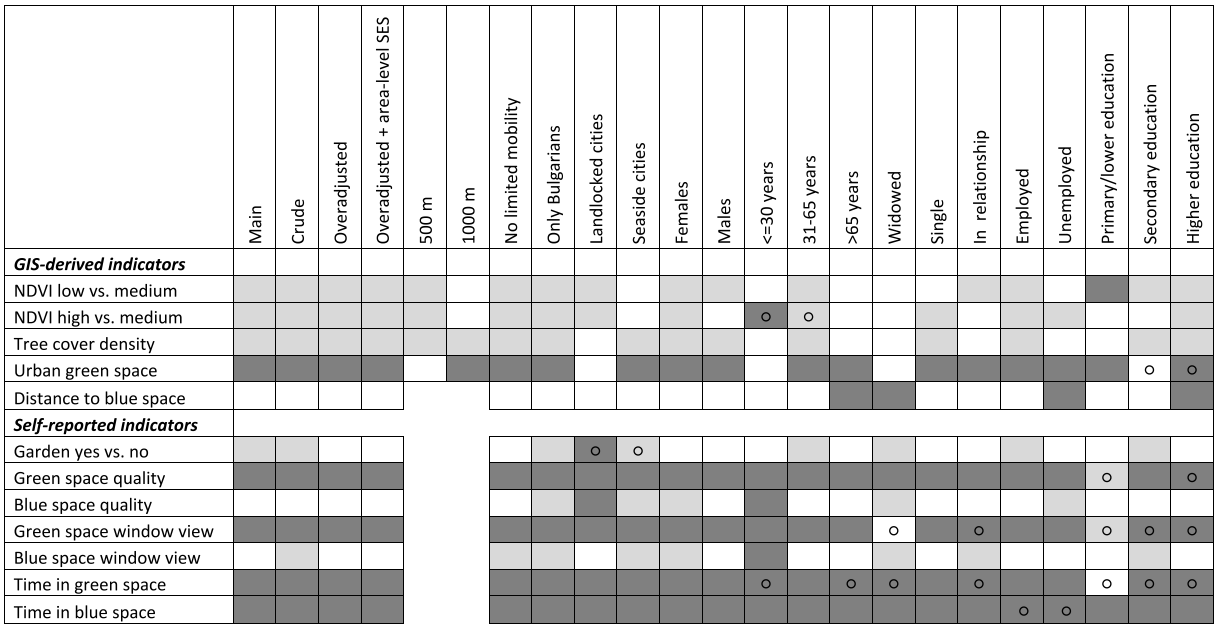
High NDVI was related to lower loneliness scores among participants $\leq$ 30 years, while the opposite was observed in the 31-to-65-year-olds (Fig. S22). Time spent in green space was related to lower loneliness scores in all age groups but strongest in participants $\leq$ 30 years (Fig. S23).

Associations with GIS-derived nature exposures were not modified by relationship status (Fig. S24). Having a green space window view was related to less loneliness in participants in relationships but showed no association in widowed participants (Fig. S25). More time spent in green space was less "beneficial" for widowed participants than for participants with partners.

There was no effect modification of associations with GIS-derived (Fig. S26) or self-reported (Fig. S27) nature exposures by employment status except that the "beneficial" association with time spent in blue space was stronger for unemployed than for employed participants.

A higher percentage of urban green space was associated with less loneliness in participants with higher education but had no such relation

Table 2
Summary of regression results. Light grey cells stand for "harmful", dark grey cells for "beneficial", and white cells for null associations. The cells without border indicate that the buffer-related sensitivity analyses are not applicable for non-buffer-based exposures. Circles denote presence of effect modification.



in participants with secondary education (Fig. S28). Green space quality and green space window view were related to higher loneliness scores in participants with primary or lower education but with lower loneliness scores in participants with higher education, and in the case of green space window view also in participants with secondary education (Fig. S29). Time spent in green space showed a "beneficial" association in participants with secondary or higher education but no association for participants with primary or lower education.

Table 2 summarises regression results for all strata and indicates effect modifications. All numerical estimates can be found in Supplement 2.

4. Discussion

4.1. Main findings

The results of our cross-sectional analysis in a population-based sample of 3604 Bulgarian urban adults suggest that residing in areas with more urban green space, higher green space quality and more green space window view, as well as spending more time in green space and blue space are associated with less loneliness. Living in low or high compared to medium level NDVI settings or in areas with higher tree cover density was associated with higher loneliness scores. We further observed some effect modification by type of city, age, relationship and employment statuses, and education.

4.2. Comparison with previous research and interpretations

The percentage of participants with high loneliness appears to be lower in our sample than the numbers reported in the EU Loneliness Survey for Bulgaria: 4.5 % vs. 16–17 %. This is not surprising given the differences between our study and the EU Loneliness Survey. We used random sampling with in-person interviews; they used convenience sampling and an online questionnaire. Both studies based their estimates on a single question but referred to different time periods (last two weeks vs. last four weeks), asked about different aspects of loneliness (in general vs. frequency), and collected answers differently (seven-point Likert scale vs. five frequency categories). Most of all, data collection happened between August and October in our study and in the dark months November and December in the EU Loneliness Survey.

We tried to relate our participants' exposure to nature to the 3-30-300 green space rule proposed by Konijnendijk (2023). While 73.7 % of them had a view on at least three trees from their home windows and 70.2 % had an urban green space within 300 m from home, less than 1 % lived in a neighbourhood with a tree cover density of 30 % or more. In other words, the 3-30-300 rule was satisfied for less than 1 % of participants and the resulting binary variable could not be used as exposure in a regression analysis. Nieuwenhuijsen et al. (2022) encountered a similar problem in Barcelona where virtually none of their participants had a tree cover density of 30 % or more around home.

In a systematic review on green space and loneliness, 66.6 % of 132 associations from 22 studies were "protective" (Astell-Burt et al., 2022b). Studies published afterwards also suggested "protective" associations (Astell-Burt et al., 2023, 2024a, 2024b; Wang et al., 2024). Among the GIS-derived indicators of exposure to nature in our study, the most consistent association in the expected direction was the one with urban green space. This finding aligns with two cross-sectional studies, a Dutch study by Maas et al. (2009) and Chinese study by Wang et al. (2024), which both revealed an association with lower odds of loneliness for the percentage of green space in 1000 m buffer neighbourhoods around home and in administratively defined neighbourhoods, respectively. However, a longitudinal Australian study (Astell-Burt et al., 2022a) has found no associations of cumulative incidence of loneliness with increased percentage of green space in 400 m and 800 m buffers. Such an association was only present with green space in a 1600 m buffer, which should be due to urban sprawl in Australia. This latter finding was replicated in another Australian study by Astell-Burt et al. (2023). We observed a nonlinear association of NDVI with loneliness where low or high as compared to medium levels of NDVI were related to higher loneliness scores. Nonlinear relationships of green space with health and well-being were reported before (e.g., Zhang et al., 2024; Zijlema et al., 2024; Markevych et al., 2014). Unlike us, four other studies reported null associations with NDVI: a UK study by Lai et al. (2021), a Spanish-Dutch-UK study by Zijlema et al. (2017), a Japanese

study by Soga et al. (2021), and a Canadian study by Villeneuve et al. (2024). Only a Chinese study by Wang et al. (2024) reported an association between higher NDVI and lower odds of loneliness. We observed that higher tree cover density was associated with higher loneliness scores. In contrast, Astell-Burt et al. (2023) found that more tree canopy was related to lower prevalence and incidence of loneliness in Australians albeit in a 1600 m buffer. Structured urban green spaces seem to be relevant for lowering loneliness in our sample of urban Bulgarian adults unlike overall level of vegetation or tree cover density, which were related to greater loneliness. This emphasises the important role of publicly accessible urban green space as a community place.

Our results for the self-reported indicators of exposure to nature were even more robust than those for the GIS-derived ones. This did not come as a surprise because the mode of measurement is known to influence the strength of correlations of characteristics of the physical environment with health and behaviours (e.g., Ding et al., 2011). Our observation that green space quality was linked to lower loneliness scores is contrary to the results from a US study where access to well-maintained safe parks within walking distance increased the odds of loneliness (Cao et al., 2020). However, and similarly to us, Soga et al. (2021) reported an inverse association between green window view and loneliness. Time spent in nature was related to less loneliness in our study. Similar observations were made in two multi-country studies – one based on Spanish, Lithuanian, Dutch, and UK data (van den Berg et al., 2017) and another based on data from Australia, India, Singapore, the UK, and the USA (Astell-Burt et al., 2024a). Furthermore, one Australian longitudinal study found that longer time spent in nature was associated with relief from loneliness though not with its incidence (Astell-Burt et al., 2024b). Another multi-country study based on data from Austria, Belgium, Canada, France, Germany, the Netherlands, the UK, and the USA produced opposite findings with longer time in nature being related to more loneliness (van Houwelingen-Snippe et al., 2020). The latter study reported no association with domestic outdoor areas, including gardens. In our study, we saw no consistent associations with presence of a domestic garden, only an effect modification by landlocked vs. seaside cities, where the detrimental association in seaside cities might be due to the higher disconnectedness of their suburbs, which is especially pronounced in Varna.

The association of high compared to medium NDVI levels with less loneliness only in the youngest group of participants might be explained by younger Bulgarians being more likely than older generations to use green spaces for socialising with their peers and partners.

Unlike in participants with secondary and especially higher education, higher green space quality and more green space window view were related to higher loneliness scores among participants with the lowest education level and time spent in green space was not associated with loneliness. We may speculate that participants with low SES might have less appreciation for green spaces just as they tend to have less environmental concern (Pampel, 2014).

4.3. Strengths and limitations

Our analysis is based on the first multi-centre population-representative health survey of Bulgarian urban adults. Nevertheless, due to missingness in the data, our analytic sample lost some of the original sample's initial external validity because participants with low perceived income were slightly underrepresented in the analytic sample. To our knowledge, this research effort to link exposure to nature with loneliness is the first of its kind in Bulgaria and, overall, in Eastern Europe. Still, the cross-sectional design made it impossible to establish causality. Reverse causality, especially in associations that relied on perceived indicators of exposure to nature, cannot be excluded. However, since our sample mainly consisted of long-time non-movers, the impact of residential self-selection should be minimal. Future studies should be longitudinal like those of Astell-Burt et al. (2022a) and Astell-Burt et al. (2023). We tried to capture diverse aspects of exposure to green and blue spaces and utilised numerous nature indicators, including four GIS-based and seven self-reported metrics. But temporal misalignment of GIS-derived indicators and survey data could have introduced measurement bias. We believe, however, that the impact of this was minimal as urban land use tends to be rather stable over time thereby preserving the spatial contrasts. Although we carefully adjusted our analyses for DAG-identified confounders and assessed effect modifications, our associations may in part be due to the impact of unmeasured confounders, like other characteristics of built environment. We tried to at least partially account for this by using multi-level modelling with a random intercept for city district. Lastly, our survey was not specifically designed to investigate associations with loneliness, and to reduce the duration of interviews and hence participant burden only a single-item question was used to obtain loneliness data. Therefore, we were unable to examine social and emotional forms of loneliness, let alone existential loneliness. Reassuringly though, single-item loneliness questions were demonstrated to be highly correlated with multi-question scales and to reliably measure loneliness in adults (Pinquart and Sörensen, 2001; Mund et al., 2023).

5. Conclusions

Higher exposure to structured urban green space and more time spent in green and blue space were associated with less loneliness in urban Bulgarian adults. Safeguarding and investing in urban public green space and improving access to the seaside, to bigger and smaller river fronts, some of which converted from brownfields, can provide more opportunities for socialising for citizens from different population strata in Bulgarian cities. On the other hand, higher vegetation degree or tree cover on their own tended to increase loneliness suggesting that merely planting more trees or creating flowerbeds on the streetside is not sufficient. Longitudinal studies can reveal more specific trends, patterns, and mechanisms that could be even more helpful for urban governance, planning, design, and management of urban public green and blue infrastructure.

CRediT authorship contribution statement

Iana Markevych: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Clemens Baumbach:** Writing – review & editing, Visualization, Software, Formal analysis, Data curation. **Marco Helbich:** Writing – review & editing, Software, Data curation. **Angel Burov:** Writing – review & editing, Data curation. **Donka Dimitrova:** Writing – review & editing, Data curation. **Mark J. Nieuwenhuijsen:** Writing – review & editing, Data curation. **Angel M. Dzhambov:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Data curation.

Data availability and sharing

The survey data are bound to the local ethical and legal restrictions. The informed consent provided by the study participants did not include study data being posted in public databases. However, all data used for this study are available based on a data transfer agreement upon a reasonable request to Angel M. Dzhambov (Angel.Dzhambov@mu-plovdiv.bg).

Declaration of generative AI in scientific writing

No generative AI and AI-assisted technologies were used during the preparation of this work.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2025.103509.

Data availability

Data will be made available on request.

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