International Journal of Hygiene and Environmental Health 276 (2026) 114831

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

Residential green space and incidence of cardiovascular disease: Evidence from a nationwide population-based study

Junhyun Kwon [a], Hyeon Chang Kim [b,c], Eunji Kim [d], YunJae Jung [e,f,g], Eunji Kim [a,h,*]

[a] Artificial Intelligence and Big-Data Convergence Center, Gil Medical Center, Gachon University College of Medicine, Incheon, South Korea
[b] Department of Preventive Medicine, Yonsei University College of Medicine, Seoul, South Korea
[c] Institute for Innovation in Digital Healthcare, Yonsei University, Seoul, South Korea
[d] School of Computing and Information Systems, University of Melbourne, Parkville, Australia
[e] Department of Microbiology, Gachon University College of Medicine, Incheon, South Korea
[f] Lee Gil Ya Cancer and Diabetes Institute, Gachon University, Incheon, South Korea
[g] Department of Health Science and Technology, Gachon Advanced Institute for Health Science & Technology, Gachon University, Incheon, South Korea
[h] Department of Preventive Medicine, Gachon University College of Medicine, Incheon, South Korea

ARTICLE INFO

Keywords:
Green space
Cardiovascular diseases
Environmental exposure
Urbanization
Cohort studies

ABSTRACT

Residential green space may be an environmental determinant of cardiovascular disease (CVD); however, longitudinal evidence based on structural measures of green space in nationwide populations remains limited in South Korea. We investigated the association between the proportion of residential green space and incident CVD, with particular attention paid to variation by degree of urbanization. Data from the National Health Insurance Service–National Sample Cohort, including 321,999 participants without prior CVD who underwent health examinations between 2010 and 2012, were analyzed. Residential green space, quantified as the proportion of park area at the municipal level, was categorized into quartiles. Incident CVD was identified using ICD-10 codes for acute myocardial infarction (I21–I23), heart failure (I50), and cerebrovascular diseases (I60–I64). Cox proportional hazards models were used to estimate adjusted hazard ratios (aHRs) with adjustments for demographic, socioeconomic, behavioral, and clinical factors. A higher proportion of residential green space was associated with a lower risk of incident CVD. Individuals in the highest quartile was had a 17% lower risk of CVD compared with the lowest quartile (aHR = 0.83, 95% CI: 0.78-0.88), with a significant dose-response relationship across quartiles (p for trend <0.001). Among all area types, the inverse association between green space and CVD risk was statistically significant in the highest quartile, with a more consistent dose–response pattern observed in metropolitan areas. These findings suggest that greater residential green space contributes to a lower CVD risk, supporting the role of green environments in public health strategies for CVD prevention.

1. Introduction

Cardiovascular disease (CVD) remains a major global public health concern (Fuster et al., 2011; Chong et al., 2025), and is the second leading cause of death in Korea (Statistics Korea, 2025), accounting for a significant proportion of the national disease burden and healthcare expenditure (Kim and Han, 2023; Kang et al., 2025). Although traditional risk factors such as hypertension, diabetes, and dyslipidemia are well established, increasing attention has been directed towards the role of individual living environments and residential characteristics in shaping cardiovascular health (Lai et al., 2023; Liu et al., 2024). In the context of accelerating urbanization, the quality of the residential environment has emerged as a key determinant of health disparities (Patil, 2014; Cacciatore et al., 2025).

Residential green space has been increasingly recognized as a modifiable environmental determinant of cardiovascular health (Yeager et al., 2018; Chen et al., 2020; Keith et al., 2024), as it constitutes an element of the built environment that can be influenced by urban planning and land-use policies. Green spaces can be modified at the community level and have been proposed to affect cardiovascular health through multiple pathways, including increased physical activity, stress reduction, enhanced social cohesion, and mitigation of environmental

* Corresponding author. Department of Preventive Medicine, Gachon University College of Medicine 38-13 Dokjeom-ro 3-beon-gil, Namdong-gu, Incheon, 21565, South Korea.

E-mail address: eunjikim@gachon.ac.kr (E. Kim).

https://doi.org/10.1016/j.ijheh.2026.114831
Received 20 January 2026; Received in revised form 5 May 2026; Accepted 22 May 2026
Available online 28 May 2026
1438-4639/

hazards, such as air pollution and noise (Chen et al., 2020; Keith et al., 2024).

Numerous international studies have reported an inverse association between green space exposure and the risk of CVD or mortality, often utilizing satellite-based vegetation indices, such as the Normalized Difference Vegetation Index or Enhanced Vegetation Index (Twohig-Bennett and Jones, 2018; Orioli et al., 2019; Rojas-Rueda et al., 2019; Yang et al., 2020; Liu et al., 2022; Paoin et al., 2023). These indices provide objective, spatially comprehensive measures of vegetation presence or density (Gascon et al., 2016; Martinez and Labib, 2023); however, they predominantly capture the biophysical characteristics of vegetation and may inadequately reflect the structural or functional attributes of green spaces that are most relevant to everyday human use (Ye et al., 2019; Martinez and Labib, 2023). For example, satellite-derived greenness measures may encompass agricultural land, forested areas, or roadside vegetation that are difficult to access or use and, therefore, may not translate into health-promoting behaviors such as physical activity or social interaction.

Public parks, as green spaces explicitly designed for accessibility, represent a key component of urban green infrastructure associated with favorable health outcomes and health-related behaviors among local populations (Sugiyama et al., 2008; Maas et al., 2009). Nevertheless, large-scale longitudinal studies examining the association between administratively defined park areas and incident CVD remain limited, particularly in Asian countries characterized by high population density and rapid urbanization.

Moreover, evidence regarding potential heterogeneity in the cardiovascular health effects of green space across different levels of urbanization remains scarce. Metropolitan, urban, and rural areas differ substantially in population density, land-use patterns, and environmental exposure, and these contextual factors may influence the association between green space and cardiovascular health. However, many previous studies have not systematically evaluated whether or how the relationship between green space and incident CVD varies according to the degree of urbanization.

Therefore, this study aimed to investigate the association between residential green space and the incidence of CVD in a nationwide population-based cohort, using the proportion of park area as an indicator of accessible green space. We further assessed whether this association differed by level of urbanization through stratified analyses for metropolitan, urban, and rural areas.

2. Materials and methods

2.1. Data source and study population

We used data from the National Health Insurance Service–National Sample Cohort (NHIS-NSC), a nationwide database from South Korea, covering the period from 2002 to 2019. The NHIS-NSC is a population-based cohort of approximately one million individuals selected through stratified random sampling to represent the Korean population by age, sex, and income level (Lee et al., 2017). The database contains detailed information on eligibility, health examinations, healthcare utilization, and mortality, supporting long-term follow-up.

The initial NHIS-NSC population from 2002 to 2019 included 1,137,861 individuals. From this population, 448,029 participants aged $\geq$19 years who underwent at least one national health examination between 2010 and 2012 were selected. The date of each participant's health examination was defined as the index date. Participants were followed from the index date until the occurrence of CVD, death, or December 31, 2019, whichever came first. To ensure the assessment of incident CVD, 29,292 individuals with a history of CVD before the index date were excluded. In addition, 1854 participants who developed CVD within one year of the index date were excluded to minimize potential reverse causation. After excluding 11 individuals with missing data on exposure variable and 9482 individuals with missing covariate data, 407,390 individuals remained in the eligible analytic population. To assess potential selection bias due to incomplete covariate data, we compared baseline characteristics between included and excluded participants (Supplementary Table S1). The primary analysis included 321,999 participants who did not change their residential area during follow-up (Fig. 1), to ensure the stability of area-based exposure assessment. Residential relocation was defined as a change in residential area type during follow-up. To maintain consistency in urbanicity classification, the primary analysis was restricted to participants who remained in the same residential area category throughout follow-up. To evaluate the robustness of the findings, supplementary analyses were conducted using the full analytical population regardless of residential relocation (Supplementary Table S2 and S3).

This study was reviewed and approved by the Institutional Review Board of Gachon University Gil Medical Center (IRB No. GBIRB2025-278), which waived the requirement for informed consent.

2.2. Assessment of residential green space

Administrative divisions in South Korea are organized hierarchically into municipalities, classified as cities (*Si* in Korean), counties (*Gun*), and districts (*Gu*). In this study, residential green space was assessed at the municipal level, encompassing to 230 administrative units based on the national classification system for the baseline period. Residential green space was operationalized as the municipality-level park-area proportion (total designated park area ÷ total land area within the municipal boundary). For each participant, the park-area proportion from the baseline year was linked to their baseline municipality.

Data on park areas were obtained from the Korean Statistical Information Service (KOSIS), which annually compiles nationwide statistics on urban and county planning facilities classified as spatial facilities under national land-use planning regulations (https://kosis.kr) (Korea Land and Geospatial Informatix Corporation, 2024). Within the KOSIS database, park areas comprise all land officially designated as parks within municipal boundaries. These designated park types encompass urban natural parks, national urban parks, small parks, children's parks, neighborhood parks, historical parks, cultural parks, waterfront parks, cemeteries, sports parks, urban agriculture parks, disaster prevention parks, and other parks established under local ordinances (Korea Land and Geospatial Informatix Corporation, 2024). These data were collected and published annually, providing a standardized measure of park development across administrative districts.

Municipalities were ranked according to the proportion of park area and categorized into quartiles (Q1–Q4), with Q1 representing the lowest and Q4 the highest. The cut-points for these quartiles were defined as follows: Q1 $\leq$ 2.61%, Q2 $>$ 2.61% to $\leq$5.18%, Q3 $>$ 5.18% to $\leq$9.27%, and Q4 $>$ 9.27%. For stratified analyses, quartiles were re-defined within metropolitan, urban, and rural areas (i.e., area-specific quartiles).

2.3. Assessment of cardiovascular disease outcome

The primary outcome of this study was the incidence of CVD during the follow-up period. Incident CVD was defined as the first hospitalization with a primary diagnosis of CVD, identified using International Classification of Diseases, 10th Revision (ICD-10) codes. Specifically, the outcomes included acute myocardial infarction (I21–I23), cerebrovascular diseases (I60–I64), and heart failure (I50). To improve the specificity of outcome ascertainment, only inpatient diagnoses were included.

CVD incidence was identified using administrative health records based on ICD-10 diagnostic codes, and only the first hospitalization for CVD occurring during follow-up was considered in the analysis. Participants with a history of CVD before the start of follow-up were excluded to ensure that all observed events represented newly diagnosed cases.

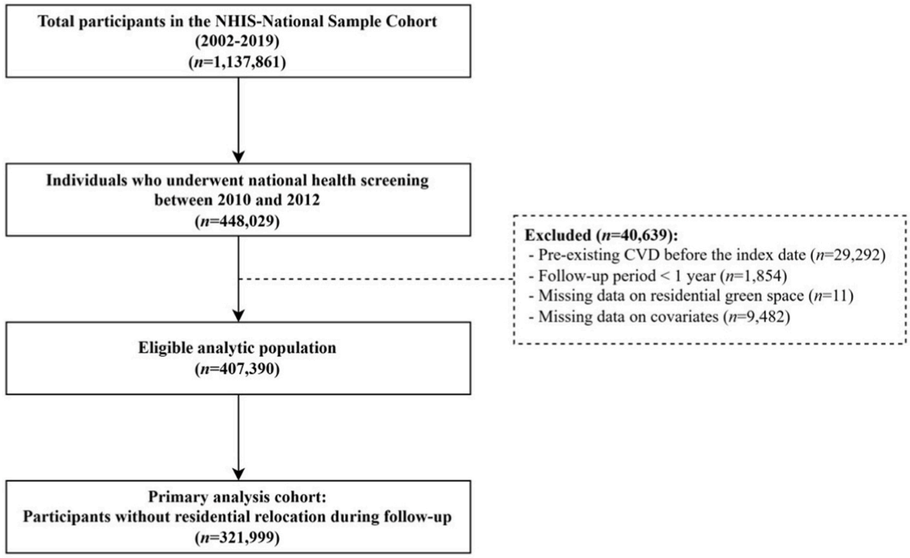

Fig. 1. Flowchart of the study population
The index date was defined as the date of the first health screening examination during the baseline period (2010–2012).

2.4. Covariates

Covariates were selected based on prior literature and their potential association with both residential green space and CVD risk. The covariates included age, sex, residential area, household income level, disability status, smoking status, and Charlson Comorbidity Index (CCI) (Charlson et al., 1987; Drosdowsky and Gough, 2022).

Residential areas were categorized into metropolitan, urban, and rural areas based on the administrative classification at the municipal level. Districts (*Gu*) within metropolitan cities, including the capital city of Seoul and the six major metropolitan cities (Busan, Daegu, Incheon, Gwangju, Daejeon, and Ulsan), were classified as metropolitan areas, while cities (*Si*) were within provinces and counties (Gun) were classified as urban and rural areas, respectively. Household income levels were determined using health insurance premium levels and categorized into tertiles. Smoking status was categorized as never smoked, former smokers, or current smokers. Participants were subsequently classified into three groups according to weekly frequency (0–1, 2–3, or ≥4 times per week). Comorbidity burden was assessed using the CCI calculated from the baseline health information.

2.5. Statistical analysis

The baseline characteristics of the study population were summarized according to quartiles of residential green space. Continuous variables were summarized as means (standard deviations), whereas categorical variables are expressed as frequencies and percentages. The association between residential green space proportion and incident CVD was examined using Cox proportional hazards regression models. The results are presented as hazard ratios (HRs) with 95% confidence intervals (CIs), with the lowest quartile of the park area proportion using the reference category. Three sequential models were constructed: (1) Model 1, unadjusted; (2) Model 2, adjusted for age and sex; and (3) Model 3, fully adjusted, including residential area, household income tertiles based on health insurance premium levels, disability status, smoking status, and CCI. These sequential models were applied to the overall population analysis; in stratified analyses by residential area, residential area was not included as a covariate.

To explore potential mediating pathways, we examined the associations between residential green space and physical activity and body mass index (BMI) defined according to Asia-Pacific criteria (World Health Organization, 2000), and assessed changes in effect estimates after additional adjustment for these variables (Supplementary Table S4 and S5). We further constructed models by sequentially adding physical activity and BMI to the fully adjusted model (Supplementary Table S6). To address potential residual confounding by area-level socioeconomic status, we conducted sensitivity analyses incorporating a municipality-level Area Deprivation Index (ADI). The ADI was constructed using four indicators reflecting area-level deprivation: the proportion of single-person households, households without a car, older adults aged ≥65 years, and individuals with less than a high school education. Each component was standardized using z-scores and aggregated into a composite ADI score, which was subsequently categorized into quartiles. Furthermore, shared frailty Cox proportional hazards models with a municipality-level random effect were fitted to account for clustering within municipalities and unobserved area-level heterogeneity (Supplementary Table S7).

The index date was defined as the date of the baseline national health examination conducted between 2010 and 2012. Annual park-area proportion data, obtained from KOSIS, were assigned according to each participant's index year and incorporated as a time-varying covariate, with values updated annually throughout the follow-up period. To minimize potential reverse causation, outcome ascertainment commenced one year after the index date. Participants were followed from one year after the baseline examination until the first occurrence of a CVD event, death, or the end of follow-up in 2019, whichever came first. Participants who did not experience an event were censored at the end of the follow-up.

To examine whether the association between the proportion of residential green space and CVD risk varied by the degree of urbanization, analyses were stratified by residential area type. All statistical analyses were performed using the SAS ver. 9.4 (SAS Institute Inc., Cary, NC, USA).

3. Results

A total of 321,999 participants were included in the analysis and categorized into quartiles (Q1–Q4) according to the proportion of park areas at the municipal level (Table 1). The mean age of participants was 48.5 ± 13.5 years, and the sex distribution was nearly equal, with 50.3% men and 49.7% women. Participants in the lowest quartile (Q1) of residential green spaces were predominantly residents of metropolitan

Table 1
General characteristics of the study population by quartiles of green space proportion.

Variable	Overall (n = 321,999)		Green space level							
			Q1 (Lowest)		Q2		Q3		Q4 (Highest)	
	N	%	N	%	N	%	N	%	N	%
Age, mean ± (SD)	48.5	(13.5)	49.3	(13.4)	48.6	(13.6)	48.3	(13.5)	47.7	(13.3)
Sex										
Male	162,034	50.3	40,168	49.9	40,709	51.2	41,385	50.4	39,772	49.8
Female	159,965	49.7	40,369	50.1	38,765	48.8	40,737	49.6	40,094	50.2
Urbanicity										
Metropolitan	141,981	44.1	52,838	65.6	23,980	30.2	27,453	33.4	37,710	47.2
Urban	153,391	47.6	18,935	23.5	45,606	57.4	49,426	60.2	39,424	49.4
Rural	26,627	8.3	8764	10.9	9888	12.4	5243	6.4	2732	3.4
Income level										
Low	70,530	21.9	18,636	23.1	16,771	21.1	18,148	22.1	16,975	21.3
Middle	125,460	39.0	32,452	40.3	30,434	38.3	32,187	39.2	30,387	38.0
High	126,009	39.1	29,449	36.6	32,269	40.6	31,787	38.7	32,504	40.7
Disability status										
Without disability	306,592	95.2	76,500	95.0	75,621	95.2	78,075	95.1	76,396	95.7
With disability	15,407	4.8	4037	5.0	3853	4.8	4047	4.9	3470	4.3
Smoking status										
Never	198,981	61.8	50,122	62.2	48,941	61.6	50,835	61.9	49,083	61.5
Former	45,967	14.3	11,000	13.7	11,489	14.5	11,610	14.1	11,868	14.9
Current	77,051	23.9	19,415	24.1	19,044	24.0	19,677	24.0	18,915	23.7
Charlson Comorbidity Index										
0	214,309	66.6	52,801	65.6	52,895	66.6	54,451	66.3	54,162	67.8
1	72,390	22.5	18,397	22.8	17,951	22.6	18,611	22.7	17,431	21.8
2	22,463	7.0	5893	7.3	5531	7.0	5758	7.0	5281	6.6
≥3	12,837	4.0	3446	4.3	3097	3.9	3302	4.0	2992	3.7
Incidence of cardiovascular diseases										
No	313,341	97.3	78,056	96.9	77,230	97.2	79,973	97.4	78,082	97.8
Yes	8658	2.7	2481	3.1	2244	2.8	2149	2.6	1784	2.2

Green space quartiles were defined based on the distribution of the residential proportion of park areas among total national green space.

areas (65.6%), whereas those in higher quartiles were more likely to reside in urban areas, with a more balanced distribution between urban (49.4%) and metropolitan (47.2%) areas observed in the highest quartile (Q4), and only a small proportion of participants residing in rural areas overall (8.3%).

In the analyses of the overall population using Cox proportional hazards models, higher residential green space was associated with a reduced risk of incident CVD (Table 2). In the unadjusted model (Model 1), compared with those for Q1, the HRs for incident CVD were 0.92 (95% CI: 0.87–0.97) for Q2, 0.85 (95% CI: 0.80–0.90) for Q3, and 0.73 (95% CI: 0.68–0.77) for Q4, indicating a stepwise decrease in risk with increasing residential green space proportion (p for trend <0.0001). After adjustment for age and sex (Model 2), the inverse association remained statistically significant for Q3 (aHR = 0.89, 95% CI: 0.84–0.95) and Q4 (aHR = 0.82, 95% CI: 0.77–0.87), while the association for Q2 was marginal (p = 0.0578).

In the fully adjusted model (Model 3), a graded inverse association was observed, with significantly lower risks in Q2 (aHR = 0.92, 95% CI: 0.87–0.98), Q3 (aHR = 0.87, 95% CI: 0.82–0.93), and Q4 (aHR = 0.83, 95% CI: 0.78–0.88) compared with Q1. A significant linear trend persisted, indicating a consistent dose–response relationship, with each quartile increase in residential green space being associated with a 6% reduction in CVD risk (p for trend <0.0001). These findings remained consistent after additional adjustment for physical activity and BMI (Supplementary Table S6). CVD outcomes were categorized into acute myocardial infarction, heart failure, and cerebrovascular disease to examine differences across specific conditions. Similar inverse associations were observed for heart failure and cerebrovascular disease, with significant linear trends across quartiles (p for trend = 0.0004 and < 0.0001, respectively). The magnitude of association was generally comparable to that observed for overall CVD (Supplementary Table S8). The results remained robust after additional adjustment for area-level socioeconomic status using the ADI and after accounting for clustering at the municipality level using shared frailty models (Supplementary Table S7).

Stratified analyses by the degree of urbanization revealed heterogeneity in the association between residential green space and CVD incidence (Table 3). In metropolitan areas, higher residential green spaces were consistently associated with a lower risk of CVD, demonstrating the most pronounced dose–response pattern among the three area types. Compared with Q1, the adjusted HRs were 0.90 (95% CI: 0.82–0.98) for Q2 and 0.84 (95% CI: 0.76–0.92) for Q3 and 0.80 (0.73–0.88) for Q4, with a significant linear trend across quartiles (p for trend <0.0001). In urban areas, only participants in Q4 showed a significantly lower risk of CVD compared with Q1 (aHR = 0.84, 95% CI: 0.77–0.92), although the overall linear trend remained significant (p for trend = 0.0003). In rural areas, only participants in Q4 of residential green space showed a lower risk of CVD (aHR = 0.84, 95% CI: 0.72–0.98), while associations in intermediate quartiles were not statistically significant. Nevertheless, a significant linear trend was observed (p for trend = 0.0128).

4. Discussion

In this nationwide, population-based cohort study with extended follow-up, a higher proportion of residential park areas was associated with a reduced risk of incident CVD. This inverse association remained robust after comprehensive adjustment for demographic factors, socioeconomic status, health-related behaviors, and comorbidity burden, as well as in sensitivity analyses. Although inverse associations were observed across metropolitan, urban, and rural areas, both the magnitude and pattern of this association varied according to the degree of urbanization.

Stratified analyses based on urbanicity further clarified these differences. In metropolitan areas, increasing levels of residential green space were associated with a clear and monotonic decrease in CVD risk, demonstrating a pronounced dose–response relationship across green space quartiles. In urban areas, the inverse association was less consistent across intermediate quartiles, with a significantly reduced risk observed only in the highest quartile, despite a statistically significant

Table 2
Association between green space quartiles and cardiovascular disease incidence using Cox proportional hazard models.

Variable	Cardiovascular diseases											
	Events	Person-years	Incidence rate	Model 1		*p*-value	Model 2		*p*-value	Model 3		*p*-value
				HR	(95% CI)		aHR	(95% CI)		aHR	(95% CI)	
Green space level[a]												
Q1 (Lowest)	2481	690,788.4	3.59	1.00	-		1.00	-		1.00	-	
Q2	2244	681,507.0	3.29	0.92	(0.87 - 0.97)	0.0031	0.95	(0.89 - 1.00)	0.0578	0.92	(0.87 - 0.98)	0.0070
Q3	2149	704,764.9	3.05	0.85	(0.80 - 0.90)	<0.0001	0.89	(0.84 - 0.95)	0.0001	0.87	(0.82 - 0.93)	<0.0001
Q4 (Highest)	1784	686,461.6	2.60	0.73	(0.68 - 0.77)	<0.0001	0.82	(0.77 - 0.87)	<0.0001	0.83	(0.78 - 0.88)	<0.0001
Trend per quartile increase[b]				0.90	(0.89 - 0.92)	<0.0001	0.94	(0.92 - 0.96)	<0.0001	0.94	(0.92 - 0.96)	<0.0001
Age							1.09	(1.09 - 1.09)	<0.0001	1.09	(1.09 - 1.09)	<0.0001
Sex												
Male							1.00	-		1.00	-	
Female							0.60	(0.57 - 0.62)	<0.0001	0.73	(0.69 - 0.77)	<0.0001
Urbanicity												
Metropolitan										0.82	(0.77 - 0.88)	<0.0001
Urban										0.91	(0.85 - 0.97)	0.0029
Rural										1.00	-	
Income level												
Low										0.99	(0.93 - 1.05)	0.6808
Middle										0.90	(0.85 - 0.95)	0.0003
High										1.00	-	
Disability status												
Without disability										0.77	(0.72 - 0.82)	<0.0001
With disability										1.00	-	
Smoking status												
Never										0.57	(0.53 - 0.60)	<0.0001
Former										0.58	(0.54 - 0.61)	<0.0001
Current										1.00	-	
Charlson Comorbidity Index												
0										0.66	(0.61 - 0.71)	<0.0001
1										0.73	(0.68 - 0.79)	<0.0001
2										0.84	(0.77 - 0.92)	<0.0001
≥3										1.00	-	

Model 1: unadjusted; Model 2: adjusted for age and sex; Model 3: additionally adjusted for urbanicity, income level, disability status, smoking status, and Charlson Comorbidity Index.

[a] Estimated from Cox proportional hazards models treating green space quartiles as categorical variables.

[b] Estimated from a separate Cox proportional hazards model treating green space quartiles as an ordinal variable to assess linear trend.

Table 3
Association between green space quartiles and cardiovascular disease stratified by urbanicity.

Variable		Cardiovascular diseases							
		N	%	Events	Person-years	Incidence rate	aHR	(95% CI)	p-value
Metropolitan	**Green space level**[a]								
	Q1 (Lowest)	37,013	26.1	1059	317,995.9	3.59	1.00	-	
	Q2	36,415	25.6	835	312,229.2	3.29	0.90	(0.82 - 0.98)	0.0210
	Q3	34,088	24.0	710	292,658.2	3.05	0.84	(0.76 - 0.92)	0.0002
	Q4 (Highest)	34,465	24.3	712	295,771.8	2.60	0.80	(0.73 - 0.88)	<0.0001
	Trend per quartile increase[b]						0.93	(0.90 - 0.96)	<0.0001
Urban	**Green space level**[a]								
	Q1 (Lowest)	38,281	25.0	1127	328,522.7	3.59	1.00	-	
	Q2	40,660	26.5	1037	349,949.7	3.29	0.92	(0.85 - 1.01)	0.0652
	Q3	36,797	24.0	969	316,842.0	3.05	0.92	(0.85 - 1.01)	0.0651
	Q4 (Highest)	37,653	24.5	805	324,163.0	2.60	0.84	(0.77 - 0.92)	0.0001
	Trend per quartile increase[b]						0.95	(0.92 - 0.98)	0.0003
Rural	**Green space level**[a]								
	Q1 (Lowest)	5846	22.0	306	49,567.8	3.59	1.00	-	
	Q2	7058	26.5	368	59,883.9	3.29	0.95	(0.82 - 1.11)	0.5149
	Q3	6109	22.9	326	51,388.8	3.05	0.89	(0.76 - 1.04)	0.1307
	Q4 (Highest)	7614	28.6	404	64,549.0	2.60	0.84	(0.72 - 0.98)	0.0215
	Trend per quartile increase[b]						0.94	(0.90 - 0.99)	0.0128

Adjusted for age, sex, income level, disability status, smoking status, and Charlson Comorbidity Index.
[a] Estimated from Cox proportional hazards models treating green space quartiles as categorical variables.
[b] Estimated from a separate Cox proportional hazards model treating green space quartiles as an ordinal variable to assess linear trend.

linear trend. A similar pattern was observed in rural areas, where only the highest quartile exhibited a significantly lower risk of CVD, although the linear trend across all quartiles remained significant. Collectively, these findings suggest that residential green space may be associated with lower CVD risk across diverse residential contexts, while indicating that both the magnitude and the dose–response pattern of the association may differ according to the level of urbanization.

These findings are consistent with previous epidemiological studies reporting beneficial associations between green space exposure and cardiovascular health outcomes (Kondo et al., 2018; Yeager et al., 2018; Chen et al., 2020; Liu et al., 2022, 2024), many of which have relied on satellite-derived vegetation indices. Such studies have demonstrated reduced risks of cardiovascular morbidity and mortality associated with higher levels of greenness (Chen et al., 2020; Liao et al., 2022). By examining incident CVD over an extended follow-up period, the present study builds on this literature and further substantiates the relevance of the residential green environment as a contextual factor in CVD prevention.

A key contribution of this study is the operationalization of residential green space as the proportion of administratively designated park areas at the municipal level. In contrast to satellite-based greenness indices, which may include agricultural land, forested regions, or other vegetated areas that are not readily accessible, park areas represent planned green infrastructure intended for routine public use. Although many prior studies have relied on satellite-derived greenness measures, several studies have also used park-based or administratively defined indicators (Dalton and Jones, 2020; Seo et al., 2019), capturing complementary aspects of green space exposure. By focusing on the proportion of designated park areas within residential settings, our approach provides a more policy-relevant measure of green space exposure. This distinction is particularly relevant in densely populated settings, where designated parks are more likely to capture meaningful opportunities for physical activity, stress reduction, and social interaction (Kaczynski and Henderson, 2008).

This measurement approach enhances the policy relevance of the findings, as park areas are directly modifiable through urban planning and land-use decisions. However, this measure should be interpreted as a structural indicator of greenness provision. It does not capture park quality, accessibility, usability, or actual park use, and therefore may only partially reflect the green space environments that residents experience in daily life.

Although the inverse association between residential green space and CVD risk was directionally consistent across levels of urbanization, variation was observed in the magnitude and pattern of the association according to the residential context. In metropolitan and urban areas, where environmental stressors such as air pollution, noise, and high population density are more prevalent, incremental increases in park availability may yield meaningful marginal benefits for cardiovascular health. In rural areas, although higher levels of residential park area tended to be associated with reduced CVD risk, the dose–response pattern across intermediate exposure categories was less clearly defined. This pattern may reflect differences in the types of green environments available in rural settings, including non-designated green spaces not captured by administratively defined park metrics.

Several plausible mechanisms may underlie the observed associations, including increased opportunities for physical activity, improvements in mental well-being, reduced exposure to air pollution and noise, and enhanced social interaction (Sugiyama et al., 2008; Aerts et al., 2018; Zuo et al., 2024). In the present cohort, smoking status was one of the strongest predictors of incident CVD, and the inverse association between residential green space and CVD risk remained robust after adjustment for smoking and other covariates, suggesting that the observed relationship is not fully explained by differences in smoking status. Nevertheless, smoking may still contribute to the green space–CVD relationship, as greener neighborhoods could be associated with lower smoking prevalence through healthier social norms and reduced chronic stress. Although these mechanisms were not comprehensively evaluated in this study, supplementary analyses suggested that physical activity may partially explain this association, whereas BMI appeared to play a limited role. These findings suggest that residential green space may operate as a population-level preventive factor that complements, rather than replaces, individual-level behavioral interventions.

This study has several strengths. First, we used a nationally representative population-based cohort with long-term follow-up allowed for a robust assessment of incident CVD. Second, by restricting the primary analysis to participants who did not change residential area type during follow-up, we improved the consistency of exposure classification, although residential moves within the same area type may still have occurred. In addition, stratified analyses by residential area type allowed for a more nuanced interpretation of the contextual differences in the association between residential green space and CVD risk.

However, this study has some limitations. Individual-level information on park use and green space-specific physical activity was unavailable, limiting our ability to assess behavioral pathways underlying the observed associations. Second, park-area proportion was measured at the municipal level and may not reflect individual access to parks within municipalities. The proportion of park areas remains a relatively crude proxy for green space availability. This measure does not capture important qualitative and functional aspects of green space, such as park quality, accessibility, usability, maintenance, and safety, nor does it reflect individual-level park use. Third, this study was unable to account for other types of green spaces beyond designated public parks, which may also contribute to cardiovascular health. Finally, the possibility of residual confounding cannot be entirely excluded. Socioeconomic status is an important potential confounder, as individuals with higher socioeconomic status are more likely to reside in greener environments and engage in healthier behaviors (Pinault et al., 2021). In this study, both individual-level income and area-level deprivation were adjusted for in the analyses. Nevertheless, as with all observational studies, residual confounding related to unmeasured or imperfectly measured socioeconomic factors may persist.

Despite these limitations, this study provides robust evidence that greater residential green space is associated with a reduced risk of CVD, particularly in more urbanized settings. The observed variation in associations across levels of urbanicity suggests that the health benefits of green space may be more pronounced in densely built environments, where natural spaces is often limited. These results highlight the importance of integrating neighborhood green infrastructure into population-based strategies for CVD prevention.

Data statement

The datasets generated and/or analyzed during the current study are not publicly available due to legal and ethical restrictions imposed by the National Health Insurance Service of Korea. Access to the NHIS data may be granted to qualified researchers upon reasonable request and approval through the official NHIS data access procedure. Aggregated data on park-area proportion were obtained from the publicly available Statistics Korea database.

Funding

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government (MSIT) [NRF-2021R1A5A2030333] and the Gachon University Research Fund of 2024 [GCU-202405170001].

CRediT authorship contribution statement

Junhyun Kwon: Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Hyeon Chang Kim:** Conceptualization, Formal analysis, Writing – review & editing. **Eunji Kim:** Conceptualization, Data curation, Writing – review & editing. **YunJae Jung:** Methodology, Supervision, Writing – review & editing. **Eunji Kim:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Supervision, Writing – review & editing.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors would like to thank the National Health Insurance Service Korea for providing access to the data used in this study and Statistics Korea for making aggregated environmental data publicly available.

Glossary

CVD	Cardiovascular disease
KOSIS	Korean Statistical Information Service
NHIS-NSC	National Health Insurance Service–National Sample Cohort
BMI	Body mass index
CCI	Charlson Comorbidity Index
HR	Hazard ratio
CI	Confidence interval
ADI	Area Deprivation Index

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2026.114831.

References

Aerts, R., Honnay, O., Van Nieuwenhuyse, A., 2018. Biodiversity and human health: mechanisms and evidence of the positive health effects of diversity in nature and green spaces. Br. Med. Bull. 127, 5–22. https://doi.org/10.1093/bmb/ldy021.

Cacciatore, S., Mao, S., Nuñez, M.V., Massaro, C., Spadafora, L., Bernardi, M., Perone, F., Sabouret, P., Biondi-Zoccai, G., Banach, M., Calvani, R., Tosato, M., Marzetti, E., Landi, F., 2025. Urban health inequities and healthy longevity: traditional and emerging risk factors across the cities and policy implications. Aging Clin. Exp. Res. 37, 143. https://doi.org/10.1007/s40520-025-03052-1.

Charlson, M.E., Pompei, P., Ales, K.L., MacKenzie, C.R., 1987. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J. Chron. Dis. 40, 373–383. https://doi.org/10.1016/0021-9681(87)90171-8.

Chen, H., Burnett, R.T., Bai, L., Kwong, J.C., Crouse, D.L., Lavigne, E., Goldberg, M.S., Copes, R., Benmarhnia, T., Ilango, S.D., van Donkelaar, A., Martin, R.V., Hystad, P., 2020. Residential greenness and cardiovascular disease incidence, readmission, and mortality. Environ. Health Perspect. 128, 87005. https://doi.org/10.1289/EHP6161.

Chong, B., Jayabaskaran, J., Jauhari, S.M., Chan, S.P., Goh, R., Kueh, M.T.W., Li, H., Chin, Y.H., Kong, G., Anand, V.V., Wang, J.W., Muthiah, M., Jain, V., Mehta, A., Lim, S.L., Foo, R., Figtree, G.A., Nicholls, S.J., Mamas, M.A., Januzzi, J.L., Chew, N. W.S., Richards, A.M., Chan, M.Y., 2025. Global burden of cardiovascular diseases: projections from 2025 to 2050. Eur. J. Prev. Cardiol. 32, 1001–1015. https://doi.org/10.1093/eurjpc/zwae281.

Dalton, A.M., Jones, A.P., 2020. Residential neighbourhood greenspace is associated with reduced risk of cardiovascular disease: a prospective cohort study. PLoS One 15, e0226524. https://doi.org/10.1371/journal.pone.0226524.

Drosdowsky, A., Gough, K., 2022. The Charlson Comorbidity Index: problems with use in epidemiological research. J. Clin. Epidemiol. 148, 174–177. https://doi.org/10.1016/j.jclinepi.2022.04.017.

Fuster, V., Kelly, B.B., Vedanthan, R., 2011. Promoting global cardiovascular health: moving forward. Circulation 123, 1671–1678. https://doi.org/10.1161/CIRCULATIONAHA.110.009522.

Gascon, M., Cirach, M., Martínez, D., Dadvand, P., Valentín, A., Plasència, A., Nieuwenhuijsen, M.J., 2016. Normalized difference vegetation index (NDVI) as a marker of surrounding greenness in epidemiological studies: the case of Barcelona city. Urban For. Urban Green. 19, 88–94. https://doi.org/10.1016/j.ufug.2016.07.001.

Kaczynski, A.T., Henderson, K.A., 2008. Parks and recreation settings and active living: a review of associations with physical activity function and intensity. J. Phys. Activ. Health 5, 619–632. https://doi.org/10.1123/jpah.5.4.619.

Kang, H.J., Wang, J., Cho, E.J., Kim, H.L., Lee, C.J., Park, J.H., Kang, J., Suh, J., Choi, K. H., Lee, S.Y., Choi, J.I., Oh, I.Y., Do, U., Roh, S.Y., Jo, S.H., Wi, J., Bae, D.H., Jung, M. H., Park, C.S., Shim, C.Y., Kang, M.K., Kim, M.N., Bae, J.W., Future and Policy Research Institute' Policy Position Paper Writing Committee, 2025. Addressing cardiovascular diseases challenges in South Korea: strategies to improve outcomes. Korean Circ. J. 55, 557–583. https://doi.org/10.4070/kcj.2024.0385.

Keith, R.J., Hart, J.L., Bhatnagar, A., 2024. Greenspaces and cardiovascular health. Circ. Res. 134, 1179–1196. https://doi.org/10.1161/CIRCRESAHA.124.323583.

Kim, K.H., Han, J.Y., 2023. Fact sheet on cardiac rehabilitation for cardiovascular disease in South Korea. Ann. Rehabil. Med. 47, 318–325. https://doi.org/10.5535/arm.23050.

Kondo, M.C., Fluehr, J.M., McKeon, T., Branas, C.C., 2018. Urban green space and its impact on human health. Int. J. Environ. Res. Publ. Health 15, 445. https://doi.org/10.3390/ijerph15030445.

Korea Land and Geospatial Informatix Corporation, 2024. Urban Planning Status (Parks). Sejong, Republic of Korea.

Lai, K.Y., Webster, C., Gallacher, J.E., Sarkar, C., 2023. Associations of urban built environment with cardiovascular risks and mortality: a systematic review. J. Urban Health 100, 745–787. https://doi.org/10.1007/s11524-023-00764-5.

Lee, J., Lee, J.S., Park, S.-H., Shin, S.A., Kim, K., 2017. Cohort profile: national health insurance service–national sample cohort (NHIS-NSC), South Korea. Int. J. Epidemiol. 46, e15. https://doi.org/10.1093/ije/dyv319.

Liao, N.S., Van Den Eeden, S.K., Sidney, S., Deosaransingh, K., Schwartz, J., Uong, S.P., Alexeeff, S.E., 2022. Joint associations between neighborhood walkability, greenness, and particulate air pollution on cardiovascular mortality among adults with a history of stroke or acute myocardial infarction. Environ. Epidemiol. 6, e200. https://doi.org/10.1097/EE9.0000000000000200.

Liu, M., Patel, V.R., Salas, R.N., Rice, M.B., Kazi, D.S., Zheng, Z., Wadhera, R.K., 2024. Neighborhood environmental burden and cardiovascular health in the US. JAMA Cardiol. 9, 153–163. https://doi.org/10.1001/jamacardio.2023.4680.

Liu, X.X., Ma, X.L., Huang, W.Z., Luo, Y.N., He, C.J., Zhong, X.M., Dadvand, P., Browning, M.H.E.M., Li, L., Zou, X.G., Dong, G.H., Yang, B.Y., 2022. Green space and cardiovascular disease: a systematic review with meta-analysis. Environ. Pollut. 301, 118990. https://doi.org/10.1016/j.envpol.2022.118990.

Maas, J., Verheij, R.A., de Vries, S., Spreeuwenberg, P., Schellevis, F.G., Groenewegen, P. P., 2009. Morbidity is related to a green living environment. J. Epidemiol. Community Health 63, 967–973. https://doi.org/10.1136/jech.2008.079038.

Martinez, A.I., Labib, S.M., 2023. Demystifying normalized difference vegetation index (NDVI) for greenness exposure assessments and policy interventions in urban greening. Environ. Res. 220, 115155. https://doi.org/10.1016/j.envres.2022.115155.

Orioli, R., Antonucci, C., Scortichini, M., Cerza, F., Marando, F., Ancona, C., Manes, F., Davoli, M., Michelozzi, P., Forastiere, F., Cesaroni, G., 2019. Exposure to residential greenness as a predictor of cause-specific mortality and stroke incidence in the Rome longitudinal study. Environ. Health Perspect. 127, 27002. https://doi.org/10.1289/EHP2854.

Paoin, K., Pharino, C., Phosri, A., Ueda, K., Seposo, X.T., Kelly, M., Seubsman, S.A., Sleigh, A., 2023. Association between greenness and cardiovascular risk factors: results from a large cohort study in Thailand. Environ. Res. 220, 115215. https://doi.org/10.1016/j.envres.2023.115215.

Patil, R.R., 2014. Urbanization as a determinant of health: a socioepidemiological perspective. Soc. Work Publ. Health 29, 335–341. https://doi.org/10.1080/19371918.2013.821360.

Pinault, L., Christidis, T., Toyib, O., Crouse, D.L., 2021. Ethnocultural and socioeconomic disparities in exposure to residential greenness within urban Canada. Health Rep. 32 (5), 3–14. https://doi.org/10.25318/82-003-x202100500001-eng.

Rojas-Rueda, D., Nieuwenhuijsen, M.J., Gascon, M., Perez-Leon, D., Mudu, P., 2019. Green spaces and mortality: a systematic review and meta-analysis of cohort studies. Lancet Planet. Health 3, e469–e477. https://doi.org/10.1016/S2542-5196(19)30215-3.

Seo, S., Choi, S., Kim, K., Kim, S.M., Park, S.M., 2019. Association between urban green space and the risk of cardiovascular disease: a longitudinal study in seven Korean metropolitan areas. Environ. Int. 125, 51–57. https://doi.org/10.1016/j.envint.2019.01.038.

Statistics Korea, 2025. Cause of death statistics in 2024. Statist. Korea. Daejeon, Korea.

Sugiyama, T., Leslie, E., Giles-Corti, B., Owen, N., 2008. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? J. Epidemiol. Community Health 62, e9. https://doi.org/10.1136/jech.2007.064287.

Twohig-Bennett, C., Jones, A., 2018. The health benefits of the great outdoors: a systematic review and meta-analysis of greenspace exposure and health outcomes. Environ. Res. 166, 628–637. https://doi.org/10.1016/j.envres.2018.06.030.

World Health Organization, 2000. The Asia-Pacific Perspective: Redefining Obesity and Its Treatment. Sydney: Health Communications Australia.

Yang, B.Y., Hu, L.W., Jalaludin, B., Knibbs, L.D., Markevych, I., Heinrich, J., Bloom, M.S., Morawska, L., Lin, S., Jalava, P., Roponen, M., Gao, M., Chen, D.H., Zhou, Y., Yu, H. Y., Liu, R.Q., Zeng, X.W., Zeeshan, M., Guo, Y., Yu, Y., Dong, G.H., 2020. Association between residential greenness, cardiometabolic disorders, and cardiovascular disease among adults in China. JAMA Netw. Open 3, e2017507. https://doi.org/10.1001/jamanetworkopen.2020.17507.

Ye, Y., Richards, D., Lu, Y., Song, X., Zhuang, Y., Zeng, W., Zhong, T., 2019. Measuring daily accessed street greenery: a human-scale approach for informing better urban planning practices. Landsc. Urban Plan. 191, 103434. https://doi.org/10.1016/j.landurbplan.2018.08.028.

Yeager, R., Riggs, D.W., DeJarnett, N., Tollerud, D.J., Wilson, J., Conklin, D.J., O'Toole, T.E., McCracken, J., Lorkiewicz, P., Xie, Z., Zafar, N., Krishnasamy, S.S., Srivastava, S., Finch, J., Keith, R.J., DeFilippis, A., Rai, S.N., Liu, G., Bhatnagar, A., 2018. Association between residential greenness and cardiovascular disease risk. J. Am. Heart Assoc. 7, e009117. https://doi.org/10.1161/JAHA.118.009117.

Zuo, W., Cheng, B., Feng, X., Zhuang, X., 2024. Relationship between urban green space and mental health in older adults: mediating role of relative deprivation, physical activity, and social trust. Front. Public Health 12, 1442560. https://doi.org/10.3389/fpubh.2024.1442560.