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Domestic gardens and morbidity: Associations between private green space and diagnosed health conditions in the Netherlands

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ABSTRACT

Background: Previous studies observed predominantly positive associations between the amount of nearby green space and a variety of health outcomes. Although nearness is assumed to be an important aspect of this association, the presence of own private green space is rarely studied. We investigated cross-sectional associations between the amount of domestic garden greenery and the prevalence of 21 health conditions.
Methods: Electronic health records of general practitioners, providing data on health conditions of individuals and where they lived for the year 2018, were linked with data from the same year on garden presence and size derived from the Netherlands' Cadastre, Land registry and Mapping Agency. Amount of garden greenery was assessed with high resolution aerial photographs. Data were available for about 800,000 persons from 294 practices. We performed multi-level logistic regression analyses with practice as second level, adjusting for multiple covariates, including socioeconomic status at individual and neighbourhood level.
Findings: Prevalence of 16 of the 21 health conditions was lower for at least the highest classes of garden greenery. The inverse association was strongest for intestinal tract infections, with an over 20 % lower prevalence if the garden contained at least 50 m^2 greenery versus no garden. Including the overall amount of greenery within 125 m of the home in the analyses did not attenuate the results. Sex was an important moderator, with many associations being stronger for women.
Conclusions: Own private green space is inversely associated with the prevalence of many health conditions, more so than other nearby green space. Responsible pathways are unclear. Further research is needed to confirm these findings and to identify the pathways underlying the cross-sectional associations. Information on pathways may also offer clues on how to compensate for the absence of a domestic garden, which is likely to become more common due to urban densification.

1. Introduction

Research on the relevance of green space in the residential environment for human health has become an established research tradition (Kim et al., 2023). By and large, studies show predominantly positive associations for a variety of health outcomes: higher self-reported overall and mental health, lower prevalence of specific mental and physical conditions, and less premature mortality (Yang et al., 2021; Dadvand et al., 2023). Research on green space in the residential environment has focused primarily on either the availability of public green space, or the total amount of greenery in this environment (Wendelboe-Nelson et al., 2019). Although the latter includes private greenery, it is usually not identified as such, nor analysed separately from public green space. Some exceptions are studies by Dennis & James (2017) and Roscoe et al. (2022), both observing positive associations between private greenery and health. However, these studies made no distinction between one's own private green space and that of one's neighbourhood members. Other studies looked at having access to a private garden. For example, De Bell et al. (2020) report that having access to a private garden was associated with higher self-reported well-being. Brindley et al. (2018) looked at how self-reported health was related to the average domestic garden size per household in urban neighbourhoods,

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including households without a domestic garden. They concluded that smaller garden sizes were associated with a higher prevalence of poor health. Garden size may be considered a proxy for the amount of garden greenery. Even so, despite what we can learn from these studies, it seems fair to state that the relevance of own private greenery for one's health has received relatively little research attention thus far.

At the same time, the research focus on the availability of greenery in the residential environment is theoretically motivated by several assumptions. First, nearness is considered a proxy for how often an individual comes into contact with greenery and/or how much time one experiences greenery (i.e., exposure in the sense of actual sensory contact). Second, many of the proposed pathways linking greenery with human health consider actual contact as a prerequisite (Marselle et al., 2021). Three, health benefits of the greenery are assumed to increase with the amount of contact, at least up to a certain point (see e.g. White et al., 2019; Corley et al., 2021). Based on these assumptions, it may be argued that possessing a domestic garden, or yard, that contains a substantial amount of greenery is likely to have a positive effect on one's health and well-being. To start with, in many cases one is likely to have a view on the own garden from one's living room window. This type of visual access has been shown to be positively associated with mental well-being (Dzhambov et al., 2021; Soga et al., 2021). Even if here is not a window view on the own garden, whenever one leaves the house, one is likely to pass through the garden. In addition, the garden is likely to be a location where individuals spend more leisure time than in a nearby public green area. For example, young children may be allowed to play in the own garden on their own and thereby on average spend more time out-of-doors than children in households without a domestic garden (Robinson et al., 2024). For adults, gardens are often a place to relax and socialize, and to connect with nature (Krols et al., 2022). In addition to these exposure-related arguments, garden design and presence of vegetation are likely to be in line with one's preferences, and therefore to be considered attractive. And although maybe not considered leisure time by everybody, vegetation requires maintenance, involving physical activities such as mowing the lawn, pruning trees and bushes, weeding, planting seeds, bulbs and flowers, harvesting vegetables. Time spent on gardening has been observed to be positively associated with mental well-being (Fjaestad et al., 2023). In line with previous Dutch research on the amount of greenery in the wider residential environment (see e.g., Maas et al., 2009), we therefore hypothesize that the presence of a domestic garden adjacent to the home, and especially the amount of greenery it contains, is positively associated with the health of the inhabitants in terms of a lower morbidity for a wide range of health conditions. The objective of this study is to test this hypothesis using a combination of national data sources, available in the Netherlands, while controlling for a variety of relevant factors.

2. Methods

2.1. Data sources

Study area and participants. The study area consisted of 188 of the 380 Dutch municipalities (in 2018). These were all municipalities for which at least for some of their inhabitants health information was available by way of electronic patient records of 294 general practitioners' (GP) practices. Only people living in the built-up area of these municipalities were included. Furthermore, people that had not lived for at least two years at the same address were excluded, for reasons explained below.

Garden presence and amount of garden greenery. Data on garden presence and its size were derived from the Netherlands' Cadastre, Land registry and Mapping Agency. To begin with, residential parcels were identified, including their boundaries and size. Only residential parcels located within a built-up area were selected to avoid issues regarding what constitutes a domestic garden rather than a farm yard. The buildings present within the parcel were removed from the parcel and their ground surface was subtracted from the size of the parcel. The remaining part of the parcel formed the garden. Note that this includes paved parts of the garden. Due to cadastral parcels being based on ownership, for blocks of rented terraced houses belonging to the same owner no boundaries of the garden associated with a particular house within that block were available. As an approximation, the garden size within the parcel was divided equally over all houses within the block. Within the cadastral dataset, residential apartment buildings can only have a collective garden. In all analyses, it was assumed that apartments do not have a private garden associated with them. Gardens needed to be at least 5 square meters to be considered present. This was done to be able to ignore 'slivers' that resulted from the GIS-analyses due to slight inaccuracies in the GIS-data, which could lead to misidentifying a domestic garden being present. The amount of garden greenery was determined using an open access national map with Normalized Difference Vegetation Index (NDVI) values, made available by PDOK, a Dutch public service platform. This map is based on detailed aerial photographs taken in the summer half year of 2018 with a resolution of 0,25 x 0,25 m. To correct for seasonal differences due to different flight dates and the preprocessing that took place in combining the aerial photographs into a national map, visual inspection of the original aerial photographs was conducted to determine a cut-off value for the NDVI-score (green vs. not green) for areas for which photographs had been taken on the same date. The accuracy of the classification of pixels was validated using independent data for seven municipalities and proved to be at least 95 % (Smits, 2021). GIS-analysis was used to determine the amount of greenery within a garden, in terms of square metres. Note that tree crowns were projected on the ground surface and considered garden greenery, regardless of what was beneath the tree. For rented terraced houses, the total amount of garden greenery within the parcel was divided over the number of houses in the block, to get an estimate per house. To be able to take non-linear associations into account, the absolute amount of garden greenery was categorized in five classes, including 'no garden present' as reference category: no garden present, < 20, 20–50, 50–120, $>= 120$ m^2 of garden greenery. The 'no garden' class contained the most people. The other four classes were about equal in size. The same NDVI-data were also used to calculate the percentage of overall greenery within 125 m from the home address, as the greenery in this small buffer resembles own garden greenery most in terms of nearness (as proxy for actual exposure).

Health outcome assessment. The Nivel Primary Care Database (NPCD) provided information on the prevalence of health conditions (whether a participant had a given condition or not) in 2018. This database encompasses electronic patient records from a still growing number number of Dutch general practitioner (GP) practices and is considered to be representative for the Netherlands (Nivel, 2020). In our 2018 dataset, 294 GP practices were involved. Residents in the Netherlands are typically registered at a practice situated in the vicinity of their home. Data on both individuals who seek medical consultation and those who do not, are available. Health problems and symptoms presented in general practice are registered according to the International Classification of Primary Care (ICPC-1; Lamberts & Wood, 1987). Morbidity figures were based on the so-called episodes of care, which include all encounters (diagnosis, treatments, consultations) in general practice for a given health problem. Episodes of disease were constructed as described by Nielen et al. (2019). For the present analyses we used data of patients with a home address located within a built-up area. A second selection criterion was that by the end of 2018, the patient had lived on the same address for at least two years. This latter selection was motivated by the idea that it would take the garden greenery some time to affect resident health. ICPC-codes from the electronic patient files were grouped into 21 types of relatively common conditions (see Table S1 in appendix A for the ICPC-codes that make up a type of condition). From now on, we will refer to the 21 types of physical and mental conditions as health conditions.

Covariates. A large number of covariates were taken into account in the analyses. Since having a domestic garden adjacent to the home (and

its size) in an urban context could be taken as an indicator of socio-economic status, special attention was paid to including covariates correcting for socioeconomic status. At the individual level the included covariates were:

- sex (2): male, female
- age (5): < 20, 20–34, 35–49, 50–64, >=65
- level of education (highest obtained, 4): low, middle, high, and unknown
- migration background (4): none, western, non-western 2nd generation, non-western 1st generation

At the household level, the following covariates were included:

- type of household (4): 1-person, couple, 1-parent family, 2-parent family
- home owner (2): no, yes
- size of living space per household member (3): < 30 m^2, 30–59 m^2, >= 60 m^2
- standardized annual household income (in k€, 5): <18, 18–26, 26–34, 34–42, >=42
- standardized household capital (in k€, 5): <0, 0–40, 40–160, 160–320, >=320
- modelled noise level (Lden in 5 dB-classes): average level within a buffer of 125 *m*
- modelled fine dust concentration (μg/m^3 PM 2.5): average level within a buffer of 125 *m*

At the neighbourhood level, the following covariates were included:

- percentage inhabitants with a non-western migration background (3): <7.5 %, 7.5–22.5 %, >=22.5 %
- percentage home-owning households (3): <45 %, 45–70 %, >=70 %
- percentage of low-income households (i.e., up till 40th percentile of the national distribution; 3): <25 %, 25–50 %, >=50 %
- percentage 1-person households (3): <28 %, 28–42 %, >=42 %
- percentage households with children (3): <30 %, 30–40 %, >=40 %
- percentage multi-family homes (3): <12 %, 12–48 %, >=48 %
- urbanicity level of neighbourhood (5): very strongly urban, strongly urban, moderately urban, little urban, not urban (based on address density)

Note that for education a category 'unknown' has been added. The reason for this is threefold. To begin with, level of education is an important component of socioeconomic status, making it important to include it in the analyses. Secondly, the level of education was missing for a substantial number of individuals, that otherwise would be excluded from the analyses. Thirdly, exploratory analyses showed that level of education was not missing at random, but more often missing among the older age categories. For a more detailed description of the covariates, see Appendix D.

2.2. Analyses

Associations between the prevalence on the one hand and domestic garden presence (yes/no) and amount of garden greenery (in 5 classes) on the other hand, were assessed for each of the 21 health conditions, using multi-level logistic regression analyses with the individual as first and GP practice as second level. All analyses adjusted for the above mentioned covariates. In a second set of analyses, the amount of greenery within a 125 m radius was added as an extra predictor, to get an impression of the relative importance of own private greenery and other nearby green space with regard to the prevalence of different health conditions. Two sets of sensitivity analyses were conducted. The first set involved assessing the influence of using neighbourhood as a second level in the analyses, rather than GP-practice. The second set involved selecting only individuals that lived at least five years at the present address (i.e., by the end of 2018). This second set was conducted as a partial check on reversed causation, i.e., people with a poor health condition moving to an apartment, and thereby no longer possessing a domestic garden. In addition to the above analyses, moderation analyses were conducted by including interaction terms in the regression model for amount of garden greenery and the following potential moderators: sex, age, level of education, home ownership, urbanicity level. Moderators were tested one-at-a-time. Note that in the case of home ownership, the analyses could also be considered sensitivity analyses, given that for rental terraced houses the information on the amount of garden greenery was less accurate than for owner-occupied homes. The multilevel logistic regression analyses were conducted using MLwiN, version 3.05. In addition, SPSS (version 25) was used for descriptive statistics. We chose to use a minimal significance level of p =< 0.005 in reporting, including for confidence intervals (Benjamin et al., 2018).

3. Results

3.1. Descriptives of study population

The study population is a good representation of the Dutch population living within a built-up area at the same address for at least two years, with 51 % females, 22 % younger than 20 and 21 % older than 64. Of the home owners, 89 % had a domestic garden adjacent to the home, whereas 48 % for the tenants did so. The total number of individuals in the dataset was 806 328. However, some variables had missing data. This was especially the case for level of education, and the reason that we included 'unknown' as a fourth category. Due to missing values for other variables, 98 % of the aforementioned individuals are included in the analyses (n = 792,779). See Tables S.2 and S.2b for a description of the study population. We checked for multicollinearity issues involving garden presence or the amount of garden greenery in single level analyses by looking at the extent to which these could be predicted by the covariates (logistic and ordered logistic regression (PLUM), respectively). In both cases, there was no multicollinearity problem (De Vries et al., 2023). Intraclass correlation coefficients (ICCs) for the basic model per health condition, i.e. the model with only covariates, were estimated using a latent threshold approach (Devine et al., 2024). The estimates were mostly quite low (< 1 %). Notably, estimated ICCs were somewhat higher for the three respiratory conditions (between 2 % and 3 %), and exceptionally high for chronic eczema (15 %; see Appendix C).

3.2. Associations between domestic garden presence and health conditions

For 11 out of the 21 conditions, the prevalence was lower when a domestic garden was present (see Table 1). The association was strongest for intestinal tract infections and stroke/brain haemorrhage; both revealing at least a 15 % lower prevalence among people with a domestic garden. Only one condition showed a higher prevalence when a garden was present, namely elbow/wrist/hand complaints.

3.3. Associations between amount of garden greenery and health conditions

For three conditions already an amount of garden greenery smaller than 20 m^2 was associated with a lower prevalence compared to not having a domestic garden: stroke/brain haemorrhage, heart disease and cancer. For eight conditions this was the case when at least 20 m^2 of garden greenery was present. For five other conditions, the prevalence was only lower in case of at least 50 m^2 of garden greenery being present. And for depression and asthma/COPD, only the highest category of garden greenery (>= 120 m^2) was associated with a lower prevalence compared to not having a garden.

Only for the prevalence of elbow/wrist/hand complaints, a positive association was observed, and only so for the smallest amount of garden

Table 1
Results of multi-level logistic regression analyses of prevalence on domestic garden being present, by condition (reference: not present; n = 792,779).

Health condition	OR (99.5 % CI)
High blood pressure	**0.9633** (0.9361–0.9913)
Heart disease	**0.8814** (0.8513–0.9127)
Stroke/brain haemorrhage	**0.8433** (0.7993–0.8898)
Neck/shoulder/back complaints	0.9916 (0.9650–1.0190)
Elbow/wrist/hand complaints	***1.0804*** (1.0265–1.1371)
Arthrosis	**0.9229** (0.8913–0.9557)
Arthritis	0.9699 (0.9264–1.0153)
Depression	0.9753 (0.9293–1.0236)
Anxiety disorder	0.9861 (0.9361–1.0387)
Attention deficit hyperactivity disorder	**0.9181** (0.8635–0.9760)
Upper respiratory tract infection	**0.9587** (0.9258–0.9927)
Bronchi(oli)tis/pneumonia	0.9627 (0.9116–1.0167)
Asthma/COPD	1.0258 (0.9952–1.0574)
Migraine/severe headache	1.0071 (0.9561–1.0609)
Severe intestinal complaints	**0.9448** (0.9035–0.9880)
Intestinal tract infection	**0.8322** (0.7628–0.9079)
Medically unexplained physical symptoms	**0.9494** (0.9281–0.9713)
Chronic eczema	**0.9649** (0.9379–0.9927)
Acute urinary tract infection	**0.9297** (0.8926–0.9684)
Diabetes	0.9727 (0.9370–1.0097)
Cancer	0.9727 (0.9370–1.0097)

Odds ratios (OR) significant at $p < 0.005$ indicating an inverse association are in **bold.** OR in ***bold italic*** indicate a significant positive association. Models included the following covariates at the individual and household level: sex, age, level of education, migration background, type of household, home ownership, size of living space, household income, household capital, noise level, fine dust concentration. Included covariates at the neighbourhood level: percentages of home-owning households, low-income households, 1-person households, households with children, and multi-family homes, level of urbanicity. For full models, see Appendix C.

greenery (< 20 m^2). For three other health conditions, this smallest garden greenery category also was associated with a higher prevalence than no garden being present, making the pattern non-monotonous for these conditions. Patterns were not monotonous for some other conditions as well. Thus, a higher amount of garden greenery was not always associated with a lower prevalence than a lower amount of garden greenery. The most notable exception was cancer, with amounts of garden greenery below 50 m^2 being associated with a lower prevalence than larger amounts. An additional analysis revealed that this was due to skin cancer (see Table 2). Finally, for anxiety disorder and migraine/severe headache, no association was observed at all.

The inverse associations with larger amounts of garden greenery (>= 50 m^2) were strongest for intestinal tract infections, with an over 20 % lower prevalence in the two highest garden greenery categories. For five other conditions, the prevalence in these two categories was at least 10 % lower than when no garden was present: stroke/brain haemorrhage, heart disease, acute urinary tract infection, MUPS, ADHD. Note that for cancer the prevalence was at least 10 % lower in the two lowest categories of garden greenery (compared to domestic garden absence).

3.3.1. Accounting for the amount of green space in the wider environment

Including the percentage of green area within 125 m as an additional predictor hardly changed the results. Only for two conditions, the parameter for this percentage itself was significant (at $p < 0.005$): Asthma/COPD (OR = 0.9991) and Diabetes (OR = 0.9984). Even in those two cases, almost no attenuation of the parameters for garden greenery occurred (see Appendix A, Table S3).

3.4. Sensitivity analyses

Using neighbourhood as a second level instead of GP-practice led to virtually the same results. All previously significant associations between amount of garden greenery and a health condition remained significant, in the same direction and with only small changes in size.

Table 2
Results of multi-level logistic regression analyses of prevalence on amount of garden greenery, by health condition (OR; 99.5 % CI); reference: no domestic garden present; n = 792,779).

Health condition	< 20 m^2	20—50 m^2	50 – 120 m^2	>= 120 m^2
High blood pressure	1.0037 (0.9688-1.0399)	**0.9665** (0.9350-0.9991)	**0.9496** (0.9176-0.9827)	**0.8845** (0.8509-0.9195)
Heart disease	**0.9145** (0.8745-0.9563)	**0.8779** (0.8426-0.9147)	**0.8662** (0.8300-0.9040)	**0.8539** (0.8136-0.8962)
Stroke/brain haemorrhage	**0.8707** (0.8107-0.9351)	**0.8509** (0.7978-0.9074)	**0.8072** (0.7545-0.8635)	**0.8467** (0.7844-0.9140)
Neck/shoulder/back complaints	***1.0653*** (1.0318-1.1000)	0.9932 (0.9627-1.0247)	**0.9293** (0.8993-0.9604)	**0.8932** (0.8602-0.9275)
Elbow/wrist/hand complaints	***1.1344*** (1.0700-1.2027)	1.0590 (0.9994-1.1221)	1.0428 (0.9806-1.1090)	1.0397 (0.9694-1.1150)
Arthrosis	0.9695 (0.9269-1.0141)	**0.9230** (0.8859-0.9617)	**0.8878** (0.8509-0.9263)	**0.9068** (0.8645-0.9512)
Arthritis	1.0284 (0.9714-1.0888)	0.9899 (0.9387-1.0438)	**0.9273** (0.8769-0.9806)	**0.8586** (0.8054-0.9155)
Depression	1.0000 (0.944-01.0593)	0.9858 (0.9327-1.0419)	0.9474 (0.8924-1.0059)	**0.8859** (0.8244-0.9519)
Anxiety disorder	0.9953 (0.9362-1.0582)	0.9890 (0.9320-1.0494)	0.9706 (0.9109-1.0343)	0.9787 (0.9090-1.0538)
Attention deficit hyperactivity disorder	0.9574 (0.8920-1.0277)	**0.9121** (0.8509-0.9777)	**0.8791** (0.8163-0.9468)	**0.8872** (0.8145-0.9663)
Upper respiratory tract infection	1.0245 (0.9844-1.0662)	**0.9543** (0.9177-0.9923)	**0.9049** (0.8678-0.9436)	**0.8402** (0.8006-0.8818)
Bronchi(oli)tis/pneumonia	1.0389 (0.9725-1.1099)	0.9437 (0.8859-1.0053)	**0.9261** (0.8664-0.9898)	**0.8922** (0.8258-0.9638)
Asthma/COPD	***1.0762*** (1.0387-1.1149)	1.0315 (0.9967-1.0675)	0.9777 (0.9426-1.0140)	**0.9297** (0.8913-0.9697)
Migraine/severe headache	1.0500 (0.9893-1.1145)	1.0074 (0.9500-1.0684)	0.9488 (0.8904-1.0110)	0.9589 (0.8908-1.0321)
Severe intestinal complaints	0.9762 (0.9244-1.0309)	0.9529 (0.9049-1.0035)	**0.9181** (0.8697-0.9693)	**0.8894** (0.8361-0.9461)
Intestinal tract infection	0.9159 (0.8287-1.0122)	**0.8139** (0.7362-0.8998)	**0.7654** (0.6859-0.8540)	**0.7010** (0.6152-0.7989)
Medically unexplained physical symptoms	1.0128 (0.9864-1.0399)	**0.9447** (0.9206-0.9694)	**0.8975** (0.8734-0.9223)	**0.8660** (0.8394-0.8934)
Chronic eczema	0.9879 (0.9562-1.0206)	**0.9642** (0.9338-0.9955)	**0.9488** (0.9173-0.9813)	**0.9067** (0.8725-0.9423)
Acute urinary tract infection	0.9900 (0.9424-1.0398)	**0.9224** (0.8801-0.9667)	**0.8978** (0.8545-0.9433)	**0.8577** (0.8104-0.9078)
Diabetes	***1.0698*** (1.0211-1.1209)	0.9825 (0.9406-1.0262)	**0.9137** (0.8723-0.9570)	**0.8172** (0.7736-0.8632)
Cancer	**0.8708** (0.8327-0.9105)	**0.8798** (0.8446-0.9164)	**0.9159** (0.8785-0.9547)	**0.9189** (0.8775-0.9622)
- Skin cancer	**0.8065** (0.7573-0.8589)	**0.8311** (0.7857-0.8791)	**0.8916** (0.8429-0.9432)	**0.9036** (0.8496-0.9609)

Odds ratios (OR) significant at $p < 0.005$ indicating an inverse association are in **bold.** OR in ***bold italic*** indicate a significant positive association. Models included the following covariates at the individual and household level: sex, age, level of education, migration background, type of household, home ownership, size of living space, household income, household capital, noise level, fine dust

concentration. Included covariates at the neighbourhood level: percentages of home-owning households, low-income households, 1-person households, households with children, and multi-family homes, level of urbanicity For full models, see Appendix C.

Only one additional parameter for elbow/wrist/hand complaints now was significant, whereas it was not in the analysis with GP-practice as second level (20–50 m2 garden greenery: OR = 1.0623). See Table S4 for details.

Limiting the analysis to residents who lived at least five years at their present address reduced the sample size to 642,720. However, results remained largely unchanged, with only two previously significant parameters becoming nonsignificant: one for high blood pressure and one for bronchi(ol)tis/pneumonia, in both cases it concerned the smallest garden greenery category. The most notable change was observed for intestinal tract infections, where the OR for over 120 m^2 of garden greenery now was 0.7463 compared to 0.7010 previously. See Table S5 for details.

3.5. Moderation analyses

Including interaction terms for sex by amount of garden greenery in the analyses showed that for twelve conditions the inverse association of their prevalence with the amount of garden greenery was stronger for women (see Appendix B, Tab B.1). That is, for at least one of the four categories of garden greenery the prevalence in women was lower than that in men, whereas for none of the other categories it was higher than in men. For six conditions, this was the case for all four categories of garden greenery (compared to no garden present): high blood pressure, neck/back/shoulder complaints, arthrosis, arthritis, ADHD, MUPS. Note that three of these six conditions involve the musculoskeletal system. For three other conditions, at least one garden greenery category was weaker inversely associated with its prevalence in women than in men (and in no category stronger): migraine/severe headache, acute urinary tract infection, cancer. Only for acute urinary tract infection, this is the case for all four garden greenery categories. For the six remaining health condition, none of the interaction parameters was significant. Thus, for the majority of conditions, sex was a moderator and in most of those cases the inverse association with their prevalence was stronger for women.

Age was a moderator for several conditions as well (see Appendix B, Tab B.2). Clear and similar patterns were observed for depression, anxiety disorder and ADHD. The youngest category (< 20) shows positive associations their prevalence for all four garden greenery categories, whereas for the four older age categories associations were less positive (or even inverse) for all four garden greenery categories. Thus, for these three mental disorders the youngest age category deviated clearly from the older ones, to the extent that for this age category the associations between their prevalence and garden greenery were positive, regardless of the amount of garden greenery (compared to no garden being present). Similar but (much) less clear patterns were observed for elbow/wrist/hand complaints, neck/back/shoulder complaints, acute urinary tract infection, MUPS, heart disease, diabetes, migraine/severe headache, and severe intestinal complaints, i.e., for at least some garden greenery categories inverse associations being stronger for some of the older age categories, often especially for the oldest age category (65 +).

For upper respiratory tract infection, a clear reversed pattern was observed. The youngest age category showed inverse associations for all four garden greenery categories, and all four older age categories showed weaker inverse (or even positive) associations for all four garden greenery categories. Similar, but (much) less clear patterns were observed for intestinal tract infections, bronchi(oli)tis/pneumonia, and eczema, i.e., with at least some interaction parameters indicating a weaker inverse association for older age categories than for the youngest one. Asthma/COPD showed a different type of pattern. Especially the 20–34 age category, and to a lesser extent the 35–49 category, showed weaker inverse associations. For the five remaining conditions, no moderation by age was observed (i.e., none of the interaction parameters was significant).

The third investigated potential moderator was the level of education (see Appendix B, Tab B.3). Inverse associations between garden greenery and the prevalence of health conditions tended to be strongest for the category 'unknown level of education' (containing relatively many elderly). This pattern was especially clear for heart disease and MUPS, and only slightly less so for arthritis, hypertension, neck/back/shoulder complaints, cancer, and arthrosis. Similar, but weaker patterns were observed for Asthma/COPD, infection of the urinary tract, ADHD, serious intestinal complaints, and diabetes. The most notable deviation from this pattern was observed for anxiety disorder. For this disorder, the category with the highest level of education showed the strongest inverse associations between its prevalence and all four categories of garden greenery.

The analyses including home ownership as moderator showed significant interaction parameters for three conditions: hypertension, infection of the upper respiratory tract, and asthma/COPD (see Appendix B, Tab B.4). The patterns were not very clear. For hypertension, inverse associations were strongest for tenants, though only for the two smallest categories of garden greenery. For infection of the upper respiratory tract, inverse associations were weaker for tenants, but only for the two largest categories of garden greenery. Finally, for asthma/COPD the inverse association with its prevalence was weaker for tenants, but only for the category of between 50 and 120 m^2 of garden greenery. Overall, whether households owned or rented a house was not an important moderator of the association between amount of garden greenery and health condition prevalence.

Concerning the urbanicity level of the neighbourhood, we observed significant modification of the association with garden greenery for five health conditions (see Appendix B, Tab B.5). However, at maximum 3 of the (4x4 =) 16 interaction parameters were significant (for asthma/COPD). Thus, like home ownership, urbanicity did not appear to be an important moderator.

4. Discussion

The analyses showed that the amount of garden greenery was inversely associated with the prevalence of the majority of investigated health conditions, in several cases quite strongly so. Two of the 21 health conditions showed no association at all, and one health condition showed a positive association, although only so for the smallest amount of garden greenery (compared to no garden being present). However, associations were not always monotonous, with larger amounts of garden greenery being associated with a lower prevalence than smaller amounts. For four health conditions the smallest amount of garden greenery was even associated with a higher prevalence than no garden being present, whereas at least some of the larger amounts of garden greenery were associated with a lower prevalence. The most notable exception was observed for cancer, with smaller amounts of garden greenery being associated with lower prevalences than larger amounts. An additional analysis showed that this was due to skin cancer. Although its prevalence was always lower among people with a garden than among those without a garden, smaller amounts of greenery were associated with a lower prevalence of skin cancer than larger amounts. A possible reason could be that when more garden greenery is present, one spends more time in that garden, with more exposure to sunlight as a result.

Including the total amount of nearby greenery within 125 m in the analyses hardly attenuated the outcomes for own garden greenery. Moreover, in those analyses the total amount of nearby greenery itself was only (inversely) associated with the prevalence of two of the 21 conditions. Therefore, own garden greenery seems more relevant for personal health than nearby public or other people's private greenery.

This could be due to differences in exposure, with garden owners spending more time in their garden than non-garden owners spend in public green spaces (Lehberger & Sparke, 2023).

Sex was an important moderator for most conditions, with inverse associations with their prevalence often being stronger for women than for men; see Ambrose et al. (2020) for a similar sex difference in the association between gardening and momentary mental well-being (mood). No data were available on how much time one spent in the garden and the activities conducted in that garden. However, a partial explanation for gender as a moderator might be that, on average, women spend more time at home and in the garden than men.

Although age frequently moderated associations between garden greenery and conditions as well, the pattern was not as clear as for sex. However, the youngest age category showed clear positive rather than inverse associations for the prevalence of all three mental disorders: anxiety disorder, depression and ADHD. Another moderator was education. Especially, the unknown education category stood out, with more inverse associations for different amounts of garden greenery being observed for the prevalence of several conditions. Older age categories, especially those aged 65+, were overrepresented within this 'unknown' category. As such, the moderating effect of education might be confounded with that of age, complementing the latter: the youngest category seems to benefit the least and the oldest category the most from garden greenery, at least for some health conditions.

Owning versus renting one's home moderated associations with the amount of garden greenery for only a few health conditions. Like with educational level, there was no straightforward pattern across these health conditions. Taken the results for level of education and home ownership together, in contrast to several other studies (Rigolon et al., 2021; De Vries & Verheij, 2022) in our study we did not find much evidence of inverse associations with prevalence being stronger for individuals with a lower socioeconomic status. Garden greenery appears to be equally relevant for health across socioeconomic strata. However, it should be noted that poorer people much less often have a domestic garden adjacent to their home, because they much more often live in an apartment (De Vries et al., 2023).

Overall, we observed only a weak inverse association for depression and no association for anxiety disorder. In a previous Dutch study (Maas et al., 2009), looking at the amount of green space in the wider residential environment (up to 1 km from home) but using similar health data, the prevalence of depression and that of anxiety showed the strongest inverse associations across 24 conditions. Moreover, for depression this was especially the case for children (up to 12 years of age), whereas in the present study garden greenery showed positive associations for the youngest age category (< 20). As for ADHD, another Dutch study showed lower ADHD-related medication use among children between 5 and 12 years of age when they had more green space within 250 m from home (De Vries et al., 2022). Studies conducted in other countries showed similar positive associations between green space in the wider residential environment and the mental health of children (Vanaken & Danckaerts, 2018). Thus, with regard to mental health conditions the present results for own garden greenery deviate considerably from those for green space in the wider residential environment observed in other studies conducted in the Netherlands as well as in other countries, especially for the youngest age category.

The strongest inverse association was observed for intestinal tract infections, especially for the youngest age category. This specific condition has not often been looked into in research on green space and human health. Maas et al. (2009) also observed an inverse association between its prevalence and green space in the wider residential environment, though not stronger than for anxiety disorder and depression. The strong association with garden greenery for this health condition might be due to people interacting differently with own garden greenery than with public green space. For adults this could be about gardening as an activity, which has been shown to be related to health outcomes, especially for women and older adults (Kingsley et al., 2021). For young children, a domestic garden can offer a place where they are allowed to play on their own and explore the natural world.

More insight in the processes by which domestic garden greenery may help to preserve health can also point to ways to compensate for the absence of a domestic garden. The fact that the strongest associations were observed for physical health conditions directs attention to mechanisms involving biological resilience, rather than mental resilience (White et al., 2023). In this regard, the mechanism put forward in the biodiversity hypothesis (Haahtela, 2019) is of interest. This hypothesis states that contact with nature may influence the composition of the human microbiome in a positive way. For empirical studies supporting this hypothesis, see for example Roslund et al. (2020) who studied a soil intervention in a daycare setting. Especially a healthier gut microbiome strengthens the functioning of the immune system. Although this hypothesis is focused on allergies, according to Wiertsema et al. (2021) it may also be applicable to other types of health conditions, such as infections.

5. Strengths and limitations

Rather than self-reports, we used objective information on garden presence and the amount of garden greenery, in combination with registry data containing information on the prevalence of a wide range of health conditions. This precludes self-selection as well as a single source or common method bias. Also the substantial size of the sample and the fact that it may be considered representative for Dutch people living within a built-up area (and living at the same address for at least two years) are strengths. Furthermore, we corrected for a large number of covariates at different levels, especially those related to socioeconomic status.

Limitations are that the study has a cross-sectional design, making it difficult to rule out alternative explanations of the observed associations to being caused by the garden greenery. Especially reversed causation, with a prior poor health condition leading to moving to an apartment, i.e. without access to a domestic garden, remains a possibility. Although sensitivity analyses including only people that lived for at least five years at the present address showed little attenuation of the associations, this does not completely rule out reversed causality. Another limitation is that in the case of rented terraced houses the amount of garden greenery could not be assessed for each house separately. It was assumed that this amount was the same for all houses within the block. Obviously, this need not be the case. However, the moderation analysis for the home being rented of owned indicates that this was not a very influential factor.

Other limitations are the unavailability of information on characteristics of garden greenery, amount of time spent in the garden and on which activities this type was spent. That type of information could help to identify the most important mechanistic pathways by which garden greenery affects one's health positively. For example, Gulyas et al. (2024) reported that the positive association between gardening in allotment and domestic gardens and self-reported health was partly mediated by food and vegetable intake. This may have played a role in our study as well. Also information on health-related lifestyle factors, such as alcohol consumption and smoking was not available. If unhealthy behavioural habits are inversely associated with garden presence and/or the amount of garden greenery, this could also provide a (partial) explanation for some of the observed associations. Such an inverse association has been observed for neighbourhood greenspace and smoking (Martin et al., 2020). More in general, in our study we made many choices regarding values for distances, duration of residence, covariates to include and their classification, and used a specific analysis technique, to explore the association between private green space and a broad variety of health outcomes. The sensitivity analyses that we performed suggest that the results are quite robust. However, it is important to replicate the study and also consider other choices and complementary analysis techniques to further explore the interplay of

factors beyond the current contribution.

6. Conclusions

The amount of garden greenery was inversely associated with the prevalence of the majority of the 21 included health conditions. Especially larger amounts of garden greenery were associated with a lower prevalence, compared to garden absence. Including the amount of greenery in the wider environment in the analyses did not attenuate these results. Therefore, the ongoing densification of cities, with evermore people living in apartments, may have unintended negative side-effects, when it comes to public health (De Vries & Chalmin-Pui, 2024). A relevant question in this regard is to what extent collective, communal or allotment gardens may fulfil the same functions as domestic gardens. Further research is needed on how well these other types of gardens can compensate for the absence of a domestic private garden with regard to health.

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CRediT authorship contribution statement

Sjerp de Vries: Resources. **Christos Baliatsas:** Writing – review & editing, Resources, Project administration, Methodology, Data curation, Conceptualization. **Robert Verheij:** Writing – review & editing, Funding acquisition. **Michel Dückers:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

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.

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Appendices A–D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2025.109450.

Data availability

Results based on calculations by WENR and NIVEL using non-public microdata from Statistics Netherlands (microdata@cbs.nl), in addition to publicly accessible environmental data.

References

Ambrose, G., Das, K., Fan, Y., Ramaswami, A., 2020. Is gardening associated with greater happiness of urban residents? A multi-activity, dynamic assessment in the Twin-Cities region, USA. Landscape and Urban Planning 198, 103776.

Benjamin, D.J., Berger, J.O., Johannesson, M., Nosek, B.A., Wagenmakers, E.J., Berk, R., Johnson, V.E., 2018. Redefine Statistical Significance. Nature Human Behaviour 2 (1), 6–10.

Brindley, P., Jorgensen, A., Maheswaran, R., 2018. Domestic gardens and self-reported health: a national population study. International Journal of Health Geographics 17 (1), 1–11.

Corley, J., Okely, J.A., Taylor, A.M., Page, D., Welstead, M., Skarabela, B., Russ, T.C., 2021. Home garden use during COVID-19: Associations with physical and mental wellbeing in older adults. Journal of Environmental Psychology 73, 101545.

Dadvand, P., de Vries, S., Bauer, N., Dayamba, D. S., Feng, X., Morand, S., ... & Yang, B. Y. (2023). The Health and Wellbeing Effects of Forests, Trees and Green Space. In Konijnendijk et al. (Eds.). Forests and Trees for Human Health: pathways, impacts, challenges and response options; a global assessment report. Vienna (Austria): IUFRO.

de Bell, S., White, M., Griffiths, A., Darlow, A., Taylor, T., Wheeler, B., Lovell, R., 2020. Spending time in the garden is positively associated with health and wellbeing: Results from a national survey in England. Landscape and Urban Planning 200, 103836.

De Vries, S., Chalmin-Pui, L.S., 2024. 7 Urban densification, access to green space, and well-being. New Perspectives on Urban Design and Mental Health, Creating Urban and Workplace Environments for Recovery and Well-being, p. 140.

De Vries, S., Kramer, H., Smits, M., Spijker, J., Verheij, R., Dückers, M., Wiegersma, S., 2023. Een groene tuin, een gezonde tuin?: Onderzoek naar het belang van privégroen bij huis voor de gezondheid van burgers [A green garden, a healthy garden? Research on the relevance of private greenery near home for the health of citizens]. Wageningen Environmental Research, Wageningen (The Netherlands).

De Vries, S., Verheij, R., 2022. Residential green space associated with the use of attention deficit hyperactivity disorder medication among Dutch children. Frontiers in Psychology 13, 948942.

Dennis, M., James, P., 2017. Evaluating the relative influence on population health of domestic gardens and green space along a rural-urban gradient. Landscape and Urban Planning 157, 343–351.

Devine, S., Uanhoro, J.O., Otto, A.R., Flake, J.K., 2024. Approaches for quantifying the ICC in multilevel logistic models: A didactic demonstration. Collabra. Psychology 10 (1).

Dzhambov, A.M., Lercher, P., Browning, M.H., Stoyanov, D., Petrova, N., Novakov, S., Dimitrova, D.D., 2021. Does greenery experienced indoors and outdoors provide an escape and support mental health during the COVID-19 quarantine? Environmental Research 196, 110420.

Fjaestad, S.L., Mackelprang, J.L., Sugiyama, T., Chandrabose, M., Owen, N., Turrell, G., Kingsley, J., 2023. Associations of time spent gardening with mental wellbeing and life satisfaction in mid-to-late adulthood. Journal of Environmental Psychology 87, 101993.

Gulyas, B.Z., Caton, S.J., Edmondson, J.L., 2024. Quantifying the relationship between gardening and health and well-being in the UK: a survey during the covid-19 pandemic. BMC Public Health 24 (1), 1–17.

Haahtela, T., 2019. A biodiversity hypothesis. Allergy 74 (8), 1445–1456.

Kim, J., de Leeuw, E., Harris-Roxas, B., Sainsbury, P., 2023. Five urban health research traditions: A meta-narrative review. Social Science & Medicine 116265.

Kingsley, J., Hadgraft, N., Owen, N., Sugiyama, T., Dunstan, D.W., Chandrabose, M., 2021. Associations of vigorous gardening with cardiometabolic risk markers for middle-aged and older adults. Journal of Aging and Physical Activity 30 (3), 466–472.

Krols, J., Aerts, R., Vanlessen, N., Dewaelheyns, V., Dujardin, S., Somers, B., 2022. Residential green space, gardening, and subjective well-being: A cross-sectional study of garden owners in northern Belgium. Landscape and Urban Planning 223, 104414.

Lamberts, H., Wood, M., 1987. ICPC, international classification of primary care. Oxford University Press, USA.

Lehberger, M., Sparke, K., 2023. How important are home gardens and spending time outside for well-being during the COVID-19 pandemic? Comparing and combining data from 2020 to 2021. Journal of Environmental Psychology 91, 102089.

Martin, L., White, M.P., Pahl, S., May, J., Wheeler, B.W., 2020. Neighbourhood greenspace and smoking prevalence: Results from a nationally representative survey in England. Social Science & Medicine 265, 113448.

Marselle, M.R., Hartig, T., Cox, D.T., De Bell, S., Knapp, S., Lindley, S., Bonn, A., 2021. Pathways linking biodiversity to human health: A conceptual framework. Environment International 150, 106420.

Nielen, M.M., Spronk, I., Davids, R., Korevaar, J.C., Poos, R., Hoeymans, N., Verheij, R. A., 2019. Estimating morbidity rates based on routine electronic health records in primary care: observational study. JMIR Medical Informatics 7 (3), e11929.

Nivel (2020). Nivel Zorgregistraties eerste lijn. URL: https://www.nivel.nl/nl/nivel-zorgregistraties-eerste-lijn/nivel-zorgregistraties-eerste-lijn.

Rigolon, A., Browning, M.H., McAnirlin, O., Yoon, H., 2021. Green space and health equity: a systematic review on the potential of green space to reduce health disparities. International Journal of Environmental Research and Public Health 18 (5), 2563.

Robinson, T., Dhamrait, G., Murray, K., Boruff, B., Duncan, J., Schipperijn, J., Christian, H., 2024. Association between preschooler outdoor play and home yard vegetation as measured by high resolution imagery: Findings from the PLAYCE study. Health & Place 85, 103178.

Roscoe, C., Mackay, C., Gulliver, J., Hodgson, S., Cai, Y., Vineis, P., Fecht, D., 2022. Associations of private residential gardens versus other greenspace types with cardiovascular and respiratory disease mortality: observational evidence from UK Biobank. Environment International 167, 107427.

Roslund, M. I., Puhakka, R., Grönroos, M., Nurminen, N., Oikarinen, S., Gazali, A. M., ... & ADELE Research Group. (2020). Biodiversity intervention enhances immune regulation and health-associated commensal microbiota among daycare children. Science advances, 6(42), eaba2578.

Smits, M. (2021). Het verifiëren van een geclassificeerde kaar voor groeninventarisatie in tuinen[Verifying a classified map for assessing greenery in gardens]. Wageningen University & Research/Hogeschool Van Hall Larenstein: internship report (available upon request).

Soga, M., Evans, M.J., Tsuchiya, K., Fukano, Y., 2021. A room with a green view: the importance of nearby nature for mental health during the COVID-19 pandemic. Ecological Applications 31 (2), e2248.

Vanaken, G.J., Danckaerts, M., 2018. Impact of green space exposure on children's and adolescents' mental health: A systematic review. International Journal of Environmental Research and Public Health 15 (12), 2668.
Wendelboe-Nelson, C., Kelly, S., Kennedy, M., Cherrie, J.W., 2019. A scoping review mapping research on green space and associated mental health benefits. International Journal of Environmental Research and Public Health 16 (12), 2081.
Wiertsema, S.P., van Bergenhenegouwen, J., Garssen, J., Knippels, L.M., 2021. The interplay between the gut microbiome and the immune system in the context of infectious diseases throughout life and the role of nutrition in optimizing treatment strategies. Nutrients 13 (3), 886.
White, M.P., Alcock, I., Grellier, J., Wheeler, B.W., Hartig, T., Warber, S.L., Fleming, L.E., 2019. Spending at least 120 minutes a week in nature is associated with good health and wellbeing. Scientific Reports 9 (1), 1–11.
White, M.P., Hartig, T., Martin, L., Pahl, S., van den Berg, A.E., Wells, N.M., van den Bosch, M., 2023. Nature-based biopsychosocial resilience: An integrative theoretical framework for research on nature and health. Environment International 108234.
Yang, B.Y., Zhao, T., Hu, L.X., Browning, M.H., Heinrich, J., Dharmage, S.C., Dong, G.H., 2021. Greenspace and human health: An umbrella review. The Innovation 2 (4).