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Review article

Residential green spaces and mortality: A systematic review

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ABSTRACT

Background: A number of studies have associated natural outdoor environments with reduced mortality but there is no systematic review synthesizing the evidence.
Objectives: We aimed to systematically review the available evidence on the association between long-term exposure to residential green and blue spaces and mortality in adults, and make recommendations for further research. As a secondary aim, we also conducted meta-analyses to explore the magnitude of and heterogeneity in the risk estimates.
Methods: Following the PRISMA statement guidelines for reporting systematic reviews and meta-analysis, two independent reviewers searched studies using keywords related to natural outdoor environments and mortality.
Discussion: Our review identified twelve eligible studies conducted in North America, Europe, and Oceania with study populations ranging from 1645 up to more than 43 million individuals. These studies are heterogeneous in design, study population, green space assessment and covariate data. We found that the majority of studies show a reduction of the risk of cardiovascular disease (CVD) mortality in areas with higher residential greenness. Evidence of a reduction of all-cause mortality is more limited, and no benefits of residential greenness on lung cancer mortality are observed. There were no studies on blue spaces.
Conclusions: This review supports the hypothesis that living in areas with higher amounts of green spaces reduces mortality, mainly CVD. Further studies such as cohort studies with more and better covariate data, improved green space assessment and accounting well for socioeconomic status are needed to provide further and more complete evidence, as well as studies evaluating the benefits of blue spaces.

Contents

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1. Introduction

About half of the world population is currently living in cities and it is projected that by 2030 three of every five persons will live in urban areas (Martine and Marshall, 2007). As the world continues to urbanize, sustainable development and liveability challenges in cities will increase (United Nations Department of Economic and Social Affairs, 2014). Certain environmental factors in urban settings, such as air pollution, noise and extremely high temperatures have been associated with increased mortality (Selander et al., 2009; Basagaña et al., 2011; Hoek et al., 2013). Some studies have suggested that natural outdoor environments might help reduce the levels of air pollution and noise, as well as extreme temperatures in cities, and therefore reduce the impact of these environmental factors on our health and life-expectancy (Shanahan et al., 2015; Wolf and Robbins, 2015). Moreover, studies have observed that people living near or having access to natural outdoor environments are more likely to be physically active and have better mental health and therefore to be healthier (Shanahan et al., 2015; Wolf and Robbins, 2015).

Previously a number of studies have associated natural outdoor environments with reduced mortality (Shanahan et al., 2015; Wolf and Robbins, 2015) but there is no systematic review synthesizing the evidence, nor a precise and global estimate of the reduction of the risk of mortality in adults in relation to these types of environments. These synthesis and estimates are of importance for healthcare professionals and policymakers while translating available evidence into salutogenic interventions and policies to improve public health in urban areas. We aimed to systematically review the evidence of an association between residential natural outdoor environments, particularly green and blue spaces (e.g. lakes, rivers, beaches, etc.), and mortality in adults. As a secondary aim we also conducted meta-analyses to explore the magnitude of and heterogeneity in the risk.

2. Materials and methods

2.1. Search strategy and selection criteria

We followed the PRISMA statement guidelines for reporting systematic reviews and meta-analysis (Moher et al., 2010). The bibliographic search was carried out by two independent reviewers (MG and MTM) using MEDLINE (National Library of Medicine) and SCOPUS search engines using keywords related to natural outdoor environments (greenspace, green space, natural environment, urban design, built environment, blue space, park, forest) combined with keywords related to mortality (mortality, survival, life expectancy). The search was limited to the English language and studies on humans and the last search was conducted on November 11th 2014. Identification and first screening of the articles were performed using the information available in the title and the abstract. Doubts regarding the inclusion or exclusion of studies were resolved by discussion between the two independent researchers. After the first selection, both reviewers read through the articles to decide whether they were eligible or not. We also checked the references of the relevant articles to find other articles following the inclusion criteria.

2.2. Study eligibility criteria and quality of the studies

Following the criteria used in a previous review on green spaces and obesity (Lachowycz and Jones, 2011), the selection criteria were: a) original research article, b) report of mortality in relation to green or blue space exposure, c) the green or blue spaces were measured objectively by use of a satellite system, land cover maps, or an assessment by trained auditors using a consistent tool, d) green or blue space exposure was assigned based on location of residence, e) green or blue space exposure was included as a separate variable within the analysis and results were reported specifically for green or blue space, even if these were not the primary aim of the study. We excluded studies which did not evaluate greenness directly (N = 1) (Donovan et al., 2013) or those reporting only on infant mortality (N = 2) (Lara-Valencia et al., 2012; Kihal-Talantikite et al., 2013).

We evaluated the basic characteristics and quality of the methodology of the studies included in the systematic review by extracting the following data: author, year of publication, country, study design, study population, sample size, exposure assessment, outcome assessment, confounding factors, and other relevant information including information on potential biases (Table 1 and see Supplemental material, Table A). The two reviewers independently worked on data extraction, evaluation of study quality and classification of the evidence. Agreement was reached via consensus. Based on an adapted version of the criteria used in a previous review (Lachowycz and Jones, 2011) (see Supplemental material, Table B) we evaluated the quality of the studies and obtained a quality score (%) for each study (see Supplemental material, Table A).

2.3. Meta-analysis

We limited the meta-analyses to those outcomes of mortality for which at least three studies were available. To conduct the meta-analyses we contacted the corresponding authors of those studies missing essential information (Table 1).

Two different approaches were conducted in which exposure was treated differently. In the first approach we calculated the risk based on a 10% increase of residential greenness (measured as the percentage of green space in an area or as the normalized difference vegetation index [NDVI]). According to the type of exposure (quartiles, IQR or unit increment) used in each study, we conducted different transformation approaches to calculate the effect estimates for an increment of 10% of the exposure. If quartiles of exposure were used in the study we calculated the difference between the mean value of the 1st and the 4th quartiles, considering that the estimated effect was for this difference. In a second step we transformed the effect estimate to obtain a new one based on an increment of 10% of the exposure. If the original study calculated the effect estimate based on the IQR of the exposure we assumed a uniform distribution of the exposure and considered that the increment of 10% of the exposure was equivalent to the IQR divided by 5. We calculated the effect estimate based on this new increment of the exposure. Finally, in those studies where the effect estimate was calculated for each unit increase of the exposure, we calculated the exposure value that corresponded to 10% of the increment with respect to the median of the exposure and calculated the new effect estimate.

In the second approach, in order to obtain risks for a higher contrast of exposure, we calculated the interquartile range increase (i.e. the difference between the first and third quartiles of greenness) as a proxy of the highest vs. the lowest categories of exposure, which in each study might represent different amounts of greenness. Except for one (Tamosiunas et al., 2014), all studies evaluated surrounding greenness – the amount of greenness within a certain distance from the residence – applying land cover maps (LCM) (Hu et al., 2008; Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012; Mitchell et al., 2011; Lachowycz and Jones, 2014) or the NDVI (Uejio et al., 2011; Villeneuve et al., 2012; Harlan et al., 2013; Wilker et al., 2014). Only one study (Tamosiunas et al., 2014) evaluated access to green spaces – the presence of a green space within a walkable distance from the residence – (Table 1). In this study the exposure was defined as the distance from the residence to the nearest park, and therefore increasing exposure represented living farther from a park (less greenness). We thus turned around the estimate in order to be able to combine the study with the other studies, in which increasing exposure represented more greenness. No studies evaluating the relationship between blue spaces and mortality were found and thus the current work only includes studies evaluating green spaces and mortality.

Table 1
Main estimations of the association between surrounding greenness or access to green spaces and mortality.

Author (year)	N/study population	Exposure type	Exposure description	Mortality outcome	Outcome description	Estimate type	Estimate provided by the study
Harlan et al. (2013), The USA	2081 CAUs Adults	Surrounding greenness at CAU (factor calculated from NDVI)	IQR = 1.16[a]	All-cause (by extreme heat)	11.4% of CAUs with at least one death	OR (95%CI)	1.19 (1.02, 1.39)[a,b]
Hu et al. (2008), The USA	Not reported Adults	"Amount" of GS at CAU (LCM)	Min, max = −52.4 to 7.1	Stroke SMR	Min, mean, max (average of all CAU) = 4.22, 8.06, 34.42	β (SD)	−0.161 (0.067)[c]
Lachowycz and Jones (2014), The UK	Not reported Adults < 75 years	% GS at CAU and 5 and 10km buffer (LCM)	Quintiles (highest vs lowest)	Circulatory causes SMR	Not reported	Rate ratio (95%CI)	0.95 (0.92, 0.98)[a]
Mitchell and Popham (2008), The UK	40,813,236 individuals All population <65 years	% GS at CAU (LCM)	Five equal interval groups (every 20% — highest vs lowest)	All-cause	366,348 cases	IRR (95%CI)	0.94 (0.93, 0.96)
				Circulatory diseases	90,433 cases		0.96 (0.93, 0.99)
				Lung cancer	25,742 cases		0.96 (0.91, 1.02)
				Intentional self-harm	12,308 cases		1.00 (0.92, 1.09)
Mitchell et al. (2011), The UK	1,625,495 individuals All ages	% GS at CAU (LCM)	Quintiles (highest vs lowest)	All-cause	Not reported	IRR (95%CI)	0.63 (0.54, 0.73)
Richardson et al. (2010), The UK Richardson and Mitchell (2010)	28.6 million individuals Adults	% GS at CAU (LCM)	Four equal interval groups (every 25% — highest vs lowest)			IRR (95%CI) by gender	
				CVD	103,711 cases	Men	0.95 (0.91, 0.98)
						Women	1.00 (0.95, 1.06)
				Respiratory disease	26,591 cases	Men	0.89 (0.83, 0.96)
						Women	0.96 (0.88, 1.05)
				Lung cancer	30,110 cases	Men	0.96 (0.90, 1.02)
						Women	1.02 (0.94, 1.11)
Richardson et al. (2010), New Zealand	1,546,405 individuals Adults (15–64 years)	% GS at CAU (LCM)	Quartiles (highest vs lowest) — mean (range) for all CAU = 42% (0–100%)	CVD	9484 cases	IRR (95%CI)	1.01 (0.91, 1.11)
				Lung cancer	2603 cases		1.12 (0.94, 1.32)
Richardson et al. (2012), The USA	43 million individuals Adults	% GS at CAU (LCM)	Three categories (highest (59%–72%) vs lowest (20%–45%))		27,000 cases	β (95%CI) by gender	
				All-cause		Men	132.9 (18.3, 247.5)
						Women	94.2 (21.8., 166.7)
				Heart disease		Men	6.5 (−62.5, 75.5)
						Women	1.9 (−42.0, 45.8)
				Diabetes		Men	4.3 (−3.06, 11.73)
						Women	4.2 (−0.8, 9.2)
				Lung cancer		Men	7.9 (−8.8, 24.6)
						Women	2.5 (8.8, 13.7)
				Motor vehicle fatalities		Men	0.6 (−8.1, 9.2)
						Women	−3.4 (−8.5, 1.7)
Tamosiunas et al. (2014), Lithuania	5112 individuals Adults (45–72 years)	Distance to the nearest green space (LCM)	Tertiles (≤347.8 m, 347.81–629.6 m, ≥629.61)	CVD	83 cases	HR (95%CI)	1.15 (0.64, 2.07)[a,d]
Uejio et al. (2011), The USA	1741 CAUs Adults	Surrounding greenness at CAU (NDVI)	IQR = 0.047[a]	All-cause (extreme heat)	3.6% of CAUs with at least one death[a]	OR (95%CI)	0.64 (0.01, 40.4)[a,b]
Villeneuve et al. (2012), Canada	574,840 individuals Adults (>35 years)	Surrounding greenness in 50 and 300 m buffers (NDVI)	IQR = 0.24	All-non accidental cause	181,110	Rate ratio (95%CI)	0.95 (0.94, 0.97)
				CVD	66,530		0.95 (0.93, 0.97)
				Respiratory disease	13,730		0.92 (0.88, 0.96)
Wilker et al. (2014), The USA	1645 individuals Adults (>21 years)	Surrounding greenness in 250 m buffer (NDVI)	Quartiles (highest vs lowest)	Post-stroke all-cause	929	HR (95%CI)	0.80 (0.65, 0.99)

CAU: census area unit; CVD: cardiovascular diseases; GS: green space; HR: hazard ratio; IQR: interquartile range; IRR: incidence rate ratio; LCM: land-cover map; NDVI: normalized difference vegetation index; OR: odds ratio; SMR: standardized mortality ratio.

[a] This information was not originally available in the corresponding manuscript and was obtained from the corresponding authors via email.

[b] In order to be able to include the study in the meta-analyses the estimates provided by the authors, which used the exposure as a continuous variable, were re-estimated by using the highest vs the lowest categories of exposure.

[c] In order to be able to include the study in the meta-analyses the estimate was converted to an OR (95%CI).

[d] In this study the exposure was defined as the distance to the nearest park, and therefore increasing exposure represented living farther from a park (less greenness). We thus turned around the estimate in order to be able to combine the study with the other studies, where increasing exposure represented more greenness.

Because of the small number of studies included in each meta-analysis, we used random effect meta-analyses, even if Cochran's Q test for heterogeneity (p > 0.05) and the I^2 statistic ($I^2 \geq 25\%$ indicating moderate heterogeneity) (Higgins and Thompson, 2002) indicated no evidence of heterogeneity. We undertook this conservative approach because heterogeneity tests have been suggested to have a limited power to detect heterogeneity when the number of studies is small (Borenstein et al., 2009). The summary estimates were weighted by the inverse variance of each study. We also evaluated the influence of each study by conducting sensitivity analyses excluding studies one by one from the main meta-analysis and fitting the meta-analyses for the rest of studies. Finally, we also produced funnel plots and conducted weighted Egger tests to evaluate potential publication bias. We used R 2.15.2 statistical software.

3. Results

A total of 706 articles were identified in MEDLINE and 99 in SCOPUS. Through other sources one article was also identified. After screening the title and the abstracts and checking for duplicates, 17 articles were chosen for full-text evaluation of which 12 were finally included in the systematic review (Fig. 1).

Most of the studies (seven) had ecological design (Hu et al., 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012; Uejio et al., 2011; Harlan et al., 2013; Lachowycz and Jones, 2014), three were cohort studies (Villeneuve et al., 2012; Tamosiunas et al., 2014; Wilker et al., 2014) and two were cross-sectional (Mitchell and Popham, 2008; Mitchell et al., 2011). The quality score of the studies ranged from 40% to 90% (see Supplemental material, Table A). Five of the 12 studies were conducted in Europe, mainly in the United Kingdom (N = 4). The rest of the studies were conducted in North America (N = 6) and one in Oceania (N = 1). There was no study conducted in Latin-America, Asia or Africa. The size of the study populations was very heterogeneous ranging from 1645 up to more than 43 million individuals and sometimes not even reported (Hu et al., 2008; Lachowycz and Jones, 2014). Two studies included population of all ages, and not exclusively adults (Mitchell and Popham, 2008; Mitchell et al., 2011) (Table 1).

Evaluation of exposure to green spaces was quite heterogeneous between studies, although in all of them exposure was based on a single point in time measurement (and not the average of measurements of several years, for instance); the most used approach was the calculation of the percentage of green space based on land-cover maps (Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012; Mitchell et al., 2011; Lachowycz and Jones, 2014), followed by the use of NDVI to define surrounding greenness (Uejio et al., 2011; Villeneuve et al., 2012; Wilker et al., 2014). Three other studies followed other approaches (Hu et al., 2008; Harlan et al., 2013; Tamosiunas et al., 2014), including the distance between residence and the nearest green space (Tamosiunas et al., 2014) (Table 1).

Four studies evaluated all-cause mortality (Mitchell and Popham, 2008; Mitchell et al., 2011; Richardson et al., 2012; Villeneuve et al., 2012). Two studies evaluated all-cause mortality due to extreme heat (Uejio et al., 2011; Harlan et al., 2013) and a cohort study evaluated all-cause mortality in patients that had previously suffered a stroke (Wilker et al., 2014); these three studies were also included in the category of all-cause mortality to conduct our meta-analysis. Regarding specific causes of death, cardiovascular disease (CVD) mortality was the most studied outcome (eight studies) (Hu et al., 2008; Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012; Villeneuve et al., 2012; Lachowycz and Jones, 2014; Tamosiunas et al., 2014), followed by lung cancer mortality (four studies) (Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012). Other specific outcomes evaluated were respiratory disease mortality (two studies) (Richardson and Mitchell, 2010; Villeneuve et al., 2012), intentional self-harm (Mitchell and Popham, 2008), diabetes (Richardson et al., 2012) and motor vehicle fatality mortality (Richardson et al., 2012), all respectively evaluated in only one study (Table 1).

Results obtained in each study are summarized in Table 1. Overall, the risk of mortality from CVD was statistically significantly reduced in five of the eight studies evaluating the association between CVD mortality and residential greenness. These reductions were small, of less than 5%, in most of the studies (Hu et al., 2008; Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Villeneuve et al., 2012; Lachowycz and Jones, 2014). Results for all-cause mortality were less consistent; two studies found a statistically significant increased risk of mortality from all-causes in greener areas (Richardson et al., 2012; Harlan et al., 2013), whereas four other studies found opposite results (Mitchell and Popham, 2008; Mitchell et al., 2011; Villeneuve et al., 2012; Wilker et al., 2014) and the latter did not find associations (Uejio et al., 2011). Finally, none of the studies found associations between residential greenness and lung cancer mortality (Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Richardson et al., 2010, 2012). For other specific causes of death there are a very limited number of studies to evaluate the evidence (Table 1).

3.1. Meta-analyses

Given the number of studies, we conducted meta-analyses for all-cause mortality, CVD mortality and lung cancer mortality. In all three cases we had to exclude one of the studies initially selected because the authors could not provide the results as requested (Richardson et al., 2012).

For each 10% increase of greenness there was a small and non-statistically significant reduction of the risk of CVD mortality [risk ratio (95%CI) = 0.993 (0.985, 1.001), p-het = 0.63, Fig. 2]. Results were similar for all-cause and lung cancer mortality, but the confidence intervals were wider (Supplemental material, Figures A and B). When introducing the exposure as high vs low categories, the risk of CVD and all-cause mortality decreased and the reduction was statistically significant [risk ratio (95%CI) = 0.96 (0.94, 0.97), p-het = 0.26, and 0.92 (0.87, 0.97), p-het < 0.001, Fig. 3 and Supplemental material, Fig. C, respectively], however for lung cancer no association was observed (Supplemental material, Fig. D). Sensitivity analyses excluding one study at the time showed similar results (see Supplemental material, Table C). Funnel plots and the Egger tests did not show evidence of publication bias for any of the three outcomes evaluated (see Supplemental material, Figs. E–G).

4. Discussion

The present systematic review shows that there are only a limited number of studies evaluating the relationship between green space and mortality and that these studies are heterogeneous in design, study population, green space assessment and covariate data. We found evidence of a reduction of the risk of CVD mortality in areas with higher residential greenness. The results of the meta-analyses conducted support this conclusion. The current review also observes some

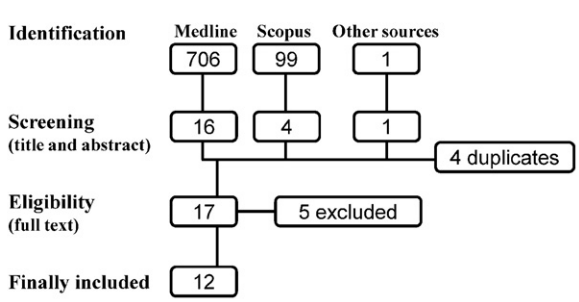

Fig. 1. Selection process of the article finally included.

evidence of the benefits of living near green spaces on all-cause mortality, but the results are less consistent. No benefits of residential greenness on lung cancer mortality are observed.

Results of the present work are consistent with those of studies that were not included in the meta-analyses because they only evaluated morbidity or only reported life expectancy. These outcomes are hard to combine with mortality estimates if little information on the population structure is available. An Australian study showed that the odds of hospitalization for heart disease or stroke were 37% lower among adults exposed to the highest tertiles of greenness compared to those exposed to the lowest tertiles (Pereira et al., 2012). A study conducted in the USA evaluating the influence on mortality of the loss of 100 million trees due to the emerald ash borer, an invasive forest pest, observed that in the infested areas mortality due to CVD and low respiratory tract illnesses was increased (Donovan et al., 2013). Other studies evaluating outcomes related to mortality, such as life expectancy or survival, also suggest beneficial effects of green spaces. Jonker et al. (2014) observed that both the quantity and the perceived quality of urban green were modestly related to healthy life expectancy, whereas the average distance to the nearest public green was not related to population health (Jonker et al., 2014). Takano et al. (2002) observed that the probability of five year survival of the senior citizens studied increased in accordance with the availability of walkable green streets and spaces near the residence (Takano et al., 2002). The current review was limited to mortality in adults, however, we are aware of the existence of two studies that also suggest that increasing greenness might reduce neonatal (Kihal-Talantikite et al., 2013) and infant (Lara-Valencia et al., 2012) mortality.

Several mechanisms have been suggested to explain the beneficial effects of green spaces (or natural outdoor environments) on life expectancy and mortality. These mechanisms include: a) intrinsic qualities of natural outdoor environments that enhance health or well-being (restoration theory) and that have an effect through simple viewing or observing natural outdoor spaces (Shanahan et al., 2015; Wolf and Robbins, 2015), b) the healthy environment associated with green spaces (increasing biodiversity which influences immune response and less temperature, air pollutants and noise have been observed in greener areas) (Gidlöf-Gunnarsson and Öhrström, 2007; Selander et al., 2009; Basagaña et al., 2011; Uejio et al., 2011; Dadvand et al., 2012; Hoek et al., 2013; Rook, 2013; Dzhambov and Dimitrova, 2014), c) the opportunity to perform physical activity (Shanahan et al., 2015; Wolf and Robbins, 2015), and d) to enhance social interactions (Bowler et al., 2010; Lachowycz and Jones, 2013). Some of these mechanisms are likely to be more associated with surrounding greenness (e.g. healthy environment) and others are more likely to be associated with access to green spaces (e.g. physical activity), although all of

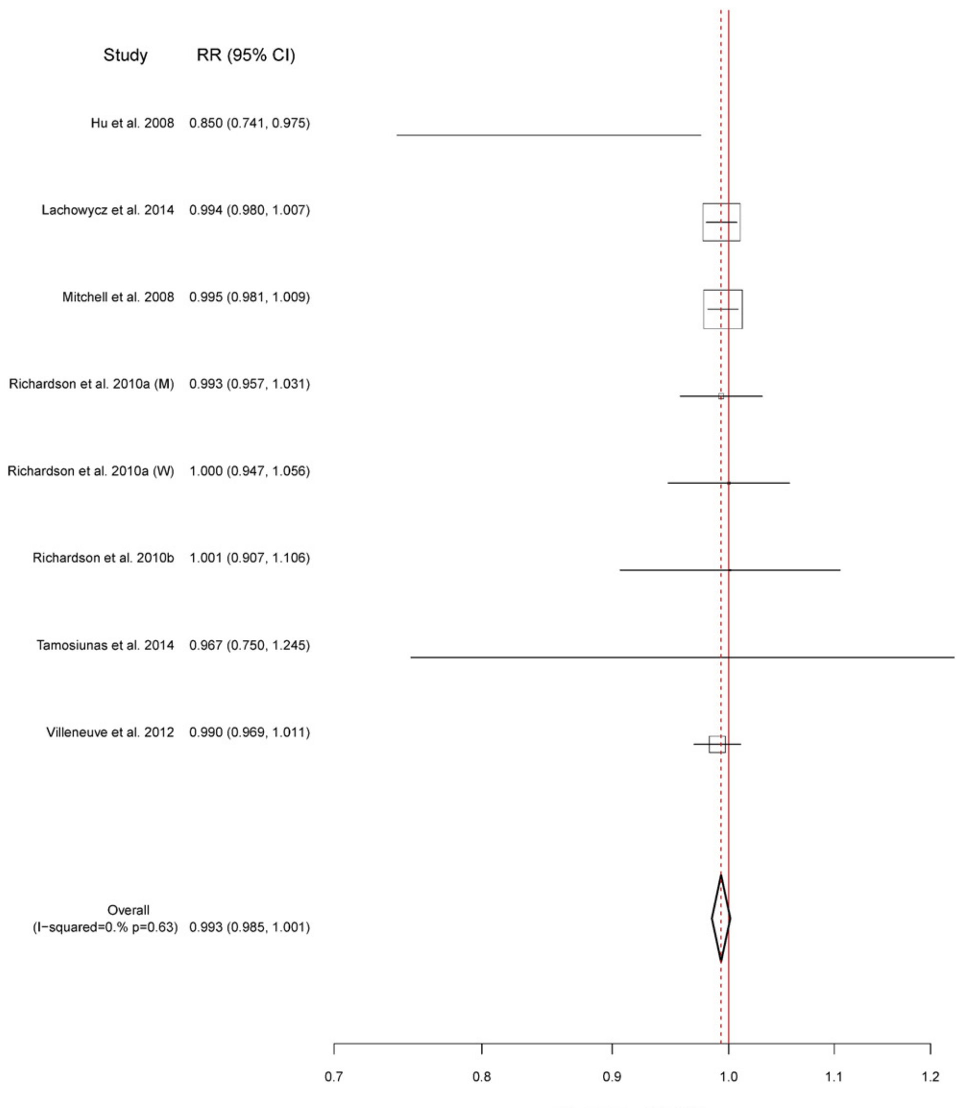

Fig. 2. Meta-analysis of the association between greenness and cardiovascular diseases (CVD) mortality for each 10% increase of greenness. M (men), W (women).

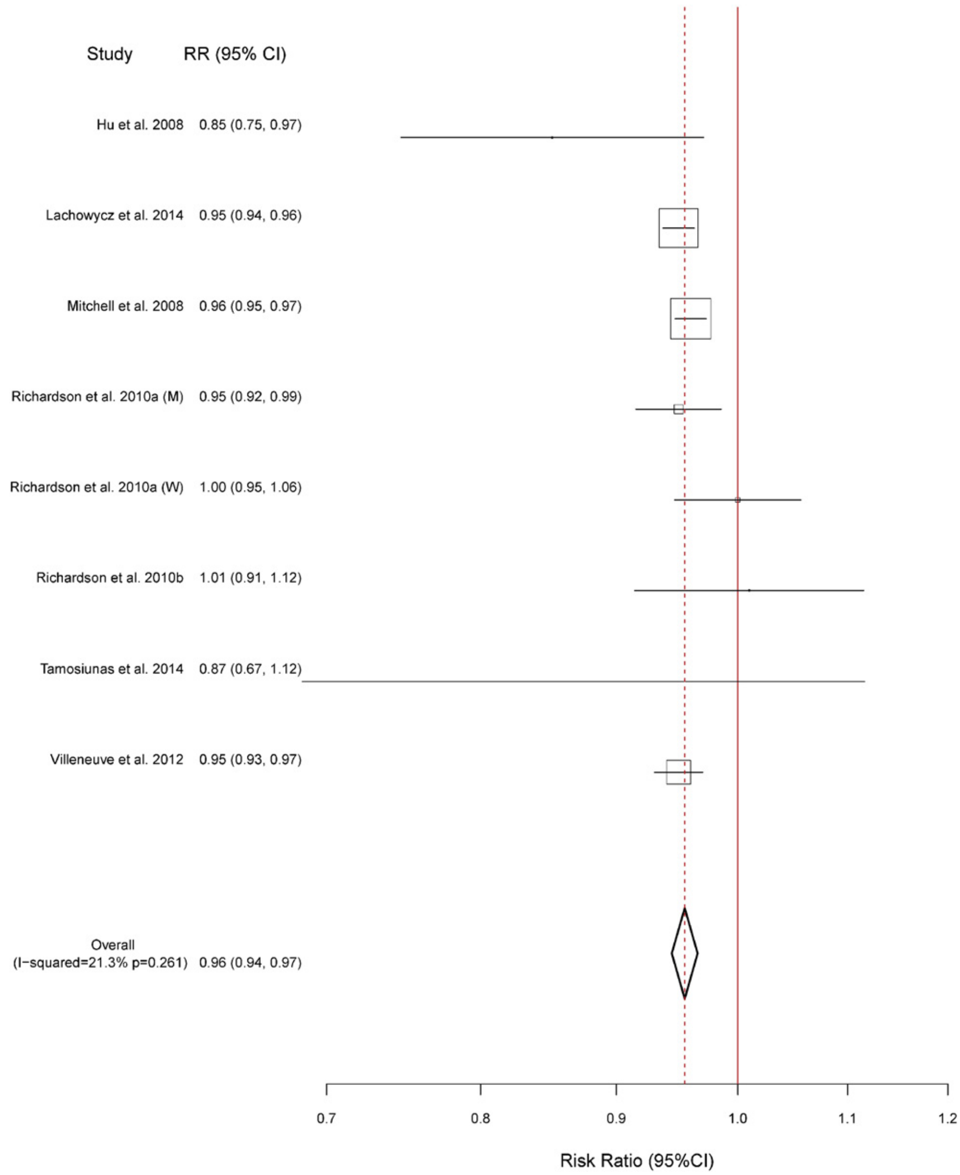

Fig. 3. Meta-analysis of the association between greenness (high vs low categories) and cardiovascular diseases (CVD) mortality. M (men), W (women).

them might be explained by a combination of both types of exposure to green spaces.

Evidence from our review supports the hypothesis that living in areas with higher amounts of green spaces reduces mortality, particularly CVD mortality. However, in the current review only one study (Tamosiunas et al., 2014) focused on the benefits of accessibility to green spaces (the distance between residence and the nearest green space). The current recommended distance between residence and the nearest open public space is 300 m (Expert group on the urban environment, 2001). This recommendation might be supported by the fact that 300–400 m is the threshold after which use of green spaces starts to quickly decline (Annerstedt et al., 2012), although some studies suggest that people are willing to walk even longer distances to access green areas (Millward et al., 2013; Lachowycz and Jones, 2014). More studies are needed to evaluate the beneficial effects of access to green spaces and the relevant distance or distances that provide such benefits.

Additionally, it is not clear what size of green space is relevant to reduce mortality or improve life expectancy. This will of course depend on the mechanisms. For instance, if physical activity is the mechanism explaining the reduced mortality associated with green spaces then possibly large green spaces are needed. However, if the reduced mortality is explained by reductions in air pollution and noise or reduction of stress due to nature viewing, then small amounts of green or greening of streets may be sufficient. Other determinants such as the quality of green spaces and how these are perceived might also be relevant, as well as other aspects of the built environment (e.g. degree of urbanization or ease of accessibility) that have been poorly explored (Nieuwenhuijsen et al., 2014). These issues need to be further studied and clarified.

4.1. Limitations of the available evidence and future research

Heterogeneity in exposure assessment was the main limitation of the current study. As already described, most studies used the percentage of green space based on land-cover maps, a few more used NDVI, and the rest (three studies) used other approaches. Additionally, most of the studies conducted the analyses using different categorizations of the exposure (quintiles, quartiles, etc), which hampered the conduct of the meta-analyses. In the current study, and being aware that the conditions to conduct metanalyses were not optimal, we were able to standardize the estimates to at least obtain a first estimation of the association between greenness and mortality. Furthermore, in a sensitivity analysis that only included studies that assessed the exposure as the percentage of green space we observed results similar to those obtained when all studies were included [e.g.: for each 10% increase of greenness the risk of CVD mortality was 0.994 (0.985, 1.004) and for the high vs low categories of exposure the risk was 0.96 (0.95, 0.97)].

A second relevant limitation is that the aim of the present review was to evaluate the effects of long-term exposure to residential natural outdoor environments on mortality. However, only one study clearly indicated that individuals that had lived in the study area for less than a year were excluded from the analyses, as authors considered that this is the minimum time to actually evaluate the effects of long-term exposure to residential green spaces. Two other studies partially considered this aspect.

The number of studies included in the current review was small, and additionally we had to leave one study out (Richardson et al., 2012). This study showed that increasing residential greenness increased the risk of all-cause mortality, but no associations were observed for specific mortality causes (heart disease, diabetes, lung cancer or automobile accidents). Also, three studies appeared to base their results on parts of the same study population (Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Mitchell et al., 2011), but after conducting the sensitivity analyses excluding these studies one at a time we obtained similar estimates (data not shown). Furthermore, despite the limited number of studies, we did not find evidence of publication bias and the results obtained were consistent (CVD mortality) or fairly consistent (all-cause mortality) after conducting the sensitivity analyses of the respective meta-analyses. Finally, another important limitation to take into consideration is that we assumed a linear exposure–response relationship, but this might not be completely true. In this sense, further studies are needed. Additionally, the results of the present work were based on studies that evaluated residential greenness using different approaches and in different geographical areas, and therefore there was considerable heterogeneity between studies regarding these aspects. However, we could combine the studies based on exposure estimates such as a 10% increase and high vs low categories of exposure. But further studies are needed to confirm the results of the current meta-analysis in different locations with different climate, urban and socio-economic characteristics and also to understand the impacts of such exposure increases in each area of study.

There are other aspects of the studies included in the present review that need some consideration. Firstly, most of the studies adjusted their model using indicators of socio-economic status at area level, and only three studies (Villeneuve et al., 2012; Harlan et al., 2013; Wilker et al., 2014) used individual data. Also regarding adjustment of the models, only four studies (Richardson and Mitchell, 2010; Richardson et al., 2010; Tamosiunas et al., 2014; Wilker et al., 2014) adjusted their models for smoking, although the lack of an association between residential greenness and lung cancer mortality provides some assurance that smoking is not likely to be an important confounder. Additionally, only half of the studies considered air pollution as a confounding factor or mediator, and none included noise in their models, two environmental factors associated with both the exposure and the outcomes of interest. However, studies included in the present review and that did adjust for air pollution still found beneficial effects of green spaces (see Supplemental material, Table A for further information on the variables included in the models). Finally, only one of the studies evaluating all-cause mortality clearly indicated that traffic accident related deaths were excluded from the analysis.

5. Conclusion

Despite the limitations described so far, this review showed evidence of an association between residential greenness and CVD mortality. This is important if we take into account that CVDs are the leading cause of mortality and years of life lost in high-income countries and that its incidence is increasing in low- and middle-income countries (Global, 2014). Future studies should evaluate effects in these countries, for which no information is currently available. Additionally, future studies should also focus on the role of social class, age or gender as potential effect modifiers of the association between residential greenness and mortality, aspects poorly explored in the studies included in the present systematic review, but that showed some effects in other relevant studies (Mitchell and Popham, 2008; Richardson and Mitchell, 2010; Lachowycz and Jones, 2014). Although, as shown, studies on green spaces and mortality have provided quite important and valuable information, in future studies more informative outcomes could be evaluated; the use of life-expectancy or even the quality-adjusted life years (QALY), which is a function of length of life and quality of life that attempts to combine the value of these attributes into a single index number (Prieto and Sacristán, 2003; Dolan, 2008), are more useful in terms of how many years longer we would live if we were exposed to green spaces and what would be the quality of these extra years. Finally, studies evaluating the associations between residential blue spaces and mortality are needed as well.

Conflict of interest

The authors declare they have no actual or potential competing financial interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.envint.2015.10.013.

References

Annerstedt, M., Ostergren, P.-O., Björk, J., Grahn, P., Skärbäck, E., Währborg, P., 2012. Green qualities in the neighbourhood and mental health — results from a longitudinal cohort study in southern Sweden. BMC Public Health 12, 337 (2012 Jan).
Basagaña, X., Sartini, C., Barrera-Gómez, J., Dadvand, P., Cunillera, J., Ostro, B., et al., 2011. Heat waves and cause-specific mortality at all ages. Epidemiology 22 (6), 765–772 (2011 Nov).
Borenstein, M., Hedges, L.V., Higgins, J.P., Rothstein, H.R., 2009. Introduction to Meta-Analysis. John Wiley and Sons, Ltd., Chichester, United Kingdom.
Bowler, D.E., Buyung-Ali, L.M., Knight, T.M., Pullin, A.S., 2010. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 10, 456 (2010 Jan).
Dadvand, P., de Nazelle, A., Triguero-Mas, M., Schembari, A., Cirach, M., Amoly, E., et al., 2012. Surrounding greenness and exposure to air pollution during pregnancy: an analysis of personal monitoring data. Environ. Health Perspect. 120 (9), 1286–1290 (2012 Sep).
Dolan, P., 2008. Developing methods that really do value the "Q" in the QALY. Health Econ. Policy Law 3 (Pt 1), 69–77 (2008 Jan).
Donovan, G.H., Butry, D.T., Michael, Y.L., Prestemon, J.P., Liebhold, A.M., Gatziolis, D., et al., 2013. The relationship between trees and human health: evidence from the spread of the emerald ash borer. Am. J. Prev. Med. 44 (2), 139–145.
Dzhambov, A.M., Dimitrova, D.D., 2014. Urban green spaces' effectiveness as a psychological buffer for the negative health impact of noise pollution: a systematic review. Noise Health 16 (70), 157–165.
Expert group on the urban environment, 2001. Towards a Local Sustainability Profile: European Common Indicators [Internet]. Office for Official Publications of the European Communities, Luxembourg (Available from: http://ec.europa.eu/environment/urban/pdf/local_sustainability_en.pdf).
Gidlöf-Gunnarsson, A., Öhrström, E., 2007. Noise and well-being in urban residential environments: the potential role of perceived availability to nearby green areas. Landsc. Urban Plan. 83 (2–3), 115–126 (2007 Nov).

Harlan, S.L., Declet-Barreto, J.H., Stefanov, W.L., Petitti, D.B., 2013. Neighborhood effects on heat deaths: social and environmental predictors of vulnerability in Maricopa County, Arizona. Environ. Health Perspect. 121 (2), 197–204 (2013 Feb).

Higgins, J.P.T., Thompson, S.G., 2002. Quantifying heterogeneity in a meta-analysis. Stat. Med. 21 (11), 1539–1558 2002 Jun 15.

Hoek, G., Krishnan, R.M., Beelen, R., Peters, A., Ostro, B., Brunekreef, B., et al., 2013. Long-term air pollution exposure and cardio-respiratory mortality: a review. Environ. Heal. 12 (1), 43 (2013 Jan).

Hu, Z., Liebens, J., Rao, K.R., 2008. Linking stroke mortality with air pollution, income, and greenness in northwest Florida: an ecological geographical study. Int. J. Health Geogr. 7, 20.

Jonker, M.F., van Lenthe, F.J., Donkers, B., Mackenbach, J.P., Burdorf, A., 2014. The effect of urban green on small-area (healthy) life expectancy. J. Epidemiol. Community Health 68 (10), 999–1002 (2014 Oct).

Kihal-Talantikite, W., Padilla, C.M., Lalloué, B., Gelormini, M., Zmirou-Navier, D., Deguen, S., 2013. Green space, social inequalities and neonatal mortality in France. BMC Pregnancy Childbirth 13, 191.

Lachowycz, K., Jones, A.P., 2011 May. Greenspace and obesity: a systematic review of the evidence. Obes. Rev. 12 (5), e183–e189.

Lachowycz, K., Jones, A.P., 2013. Towards a better understanding of the relationship between greenspace and health: development of a theoretical framework. Landsc. Urban Plan. 118, 62–69 (2013 Oct).

Lachowycz, K., Jones, A.P., 2014. Does walking explain associations between access to greenspace and lower mortality? Soc. Sci. Med. 107, 9–17.

Lara-Valencia, F., Álvarez-Hernández, G., Harlow, S.D., Denman, C., García-Pérez, H., 2012. Neighborhood socio-environmental vulnerability and infant mortality in Hermosillo, Sonora. Salud Publica Mex. 54 (4), 367–374.

Martine, G., Marshall, A., 2007. State of World Population 2007: Unleashing the Potential of Urban Growth. UNFPA.

Millward, H., Spinney, J., Scott, D., 2013. Active-transport walking behavior: destinations, durations, distances. J. Transp. Geogr. 28, 101–110 (2013 Apr.).

Mitchell, R., Astell-Burt, T., Richardson, E.A., 2011. A comparison of green space indicators for epidemiological research. J. Epidemiol. Community Health 65 (10), 853–858.

Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. Lancet 372 (9650), 1655–1660.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., 2010. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int. J. Surg. 8 (5), 336–341 (2010 Jan.).

Nieuwenhuijsen, M.J., Kruize, H., Gidlow, C., Andrusaityte, S., Antó, J.M., Basagaña, X., et al., 2014. Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol. BMJ Open 4 (4), e004951 (2014 Jan.).

Pereira, G., Foster, S., Martin, K., Christian, H., Boruff, B.J., Knuiman, M., et al., 2012. The association between neighborhood greenness and cardiovascular disease: an observational study. BMC Public Health 12 (1), 466 (2012 Jan).

Prieto, L., Sacristán, J.A., 2003. Problems and solutions in calculating quality-adjusted life years (QALYs). Health Qual. Life Outcomes 1, 80 (2003 Jan).

Richardson, E., Pearce, J., Mitchell, R., Day, P., Kingham, S., 2010. The association between green space and cause-specific mortality in urban New Zealand: an ecological analysis of green space utility. BMC Public Health 10, 240.

Richardson, E.A., Mitchell, R., 2010. Gender differences in relationships between urban green space and health in the United Kingdom. Soc. Sci. Med. 71 (3), 568–575 (2010 Aug.).

Richardson, E.A., Mitchell, R., Hartig, T., de Vries, S., Astell-Burt, T., Frumkin, H., 2012. Green cities and health: a question of scale? J. Epidemiol. Community Health 66 (2), 160–165.

Rook, G.A., 2013. Regulation of the immune system by biodiversity from the natural environment: an ecosystem service essential to health. Proc. Natl. Acad. Sci. U. S. A. 110 (46), 18360–18367 (2013 Dec. 12).

Selander, J., Nilsson, M.E., Bluhm, G., Rosenlund, M., Lindqvist, M., Nise, G., et al., 2009. Long-term exposure to road traffic noise and myocardial infarction. Epidemiology 20 (2), 272–279 (2009 Mar.).

Shanahan, D.F., Lin, B.B., Bush, R., Gaston, K.J., Dean, J.H., Barber, E., et al., 2015. Toward improved public health outcomes from urban nature. Am. J. Public Health 20, e1–e8 (2015 Jan.).

Takano, T., Nakamura, K., Watanabe, M., 2002. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. J. Epidemiol. Community Health 56 (12), 913–918 2002 Dec.

Tamosiunas, A., Grazuleviciene, R., Luksiene, D., Dedele, A., Reklaitiene, R., Baceviciene, M., et al., 2014. Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environ. Heal. 13 (1), 20.

Uejio, C.K., Wilhelmi, O.V., Golden, J.S., Mills, D.M., Gulino, S.P., Samenow, J.P., 2011. Intra-urban societal vulnerability to extreme heat: the role of heat exposure and the built environment, socioeconomics, and neighborhood stability. Health Place 17 (2), 498–507 (2011 Mar).

United Nations Department of Economic and Social Affairs, 2014. World Urbanization Prospects — The 2014 Revision - Highlights [Internet]. United Nations, New York (Available from: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf).

Villeneuve, P.J., Jerrett, M., Su, J.G., Burnett, R.T., Chen, H., Wheeler, A.J., et al., 2012. A cohort study relating urban green space with mortality in Ontario, Canada. Environ. Res. 115, 51–58.

Wilker, E.H., Wu, C.-D., McNeely, E., Mostofsky, E., Spengler, J., Wellenius, G.A., et al., 2014. Green space and mortality following ischemic stroke. Environ. Res. 133, 42–48.

Wolf, K.L., Robbins, A.S., 2015. Metro nature, environmental health, and economic value. Environ. Health Perspect. ([Epub ahead if print]). (2015 Jan 27).

Global, 2014. Regional, and national age–sex specific all-cause and cause-specific mortality for 240 causes of death, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. Lancet 385 (9963), 117–171 (2014 Dec. 17).