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.

Keywords: green spaces; blue spaces; nature; systematic review; mortality; NDVI

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 extreme 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 reducing 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 type 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 in 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 studies 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).

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 (Harlan et al. 2013)	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 (Hu et al. 2008)	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 et al. 2014, The UK (Lachowycz and Jones 2014)	Not reported Adults<75y	% 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 et al. 2008, The UK (Mitchell and Popham 2008)	40813236 individuals All population <65y	% GS at CAU (LCM)	Five equal interval groups (every 20% - highest vs lowest)	All-cause	366348 cases	IRR (95%CI)	0.94 (0.93, 0.96)
				Circulatory diseases	90433 cases		0.96 (0.93, 0.99)
				Lung cancer	25742 cases		0.96 (0.91, 1.02)
				Intentional self-harm	12308 cases		1.00 (0.92, 1.09)
Mitchell et al. 2011, The UK (Mitchell et al. 2011)	1625495 individuals All ages	% GS at CAU (LCM)	Quintiles (highest vs lowest)	All-cause	Not reported	IRR (95%CI)	0.63 (0.54, 0.73)

Author (year)	N / Study population	Exposure type	Exposure description	Mortality outcome	Outcome description	Estimate type	Estimate provided by the study
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	103711 cases	Men	0.95 (0.91, 0.98)
						Women	1.00 (0.95, 1.06)
				Respiratory disease	26591 cases	Men	0.89 (0.83, 0.96)
						Women	0.96 (0.88, 1.05)
				Lung cancer	30110 cases	Men	0.96 (0.90, 1.02)
						Women	1.02 (0.94, 1.11)
Richardson et al. 2010, New Zealand (Richardson et al. 2010)	1546405 individuals Adults (15-64y)	% 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 (Richardson et al. 2012)	43 million individuals Adults	% GS at CAU (LCM)	Three categories (highest (59%-72%) vs lowest (20%-45%))		27000 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)

Author (year)	N / Study population	Exposure type	Exposure description	Mortality outcome	Outcome description	Estimate type	Estimate provided by the study
				Motor vehicle fatalities		Men	0.6 (-8.1, 9.2)
						Women	-3.4 (-8.5, 1.7)
Tamosiunas et al. 2014, Lithuania (Tamosiunas et al. 2014)	5112 individuals Adults (45-72y)	Distance to the nearest green space (LCM)	Tertiles (≤347.8m, 347.81-629.6m, ≥629.61)	CVD	83 cases	HR (95%CI)	1.15 (0.64, 2.07)[a,d]
Uejio et al. 2011, The USA (Uejio et al. 2011)	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 (Villeneuve et al. 2012)	574840 individuals Adults (>35y)	Surrounding greenness in 50 and 300m buffers (NDVI)	IQR=0.24	All-non accidental cause	181110	Rate Ratio (95%CI)	0.95 (0.94, 0.97)
				CVD	66530		0.95 (0.93, 0.97)
				Respiratory disease	13730		0.92 (0.88, 0.96)
Wilker et al. 2014, The USA (Wilker et al. 2014)	1645 individuals Adults (>21y)	Surrounding greenness in 250m 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 further 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.

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 a 10% of the exposure. If quartiles of exposure were used in the study we calculated the difference between the mean value of the 1^{st} and the 4^{th} quartile, 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 a 10% of the exposure. If the original study calculated the effect estimate based on the IQR of the exposure we assumed a uniformed distribution of the exposure and considered that the increment of a 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 a 10% of increment with respect to the median of the exposure and calculated the new effect estimate.

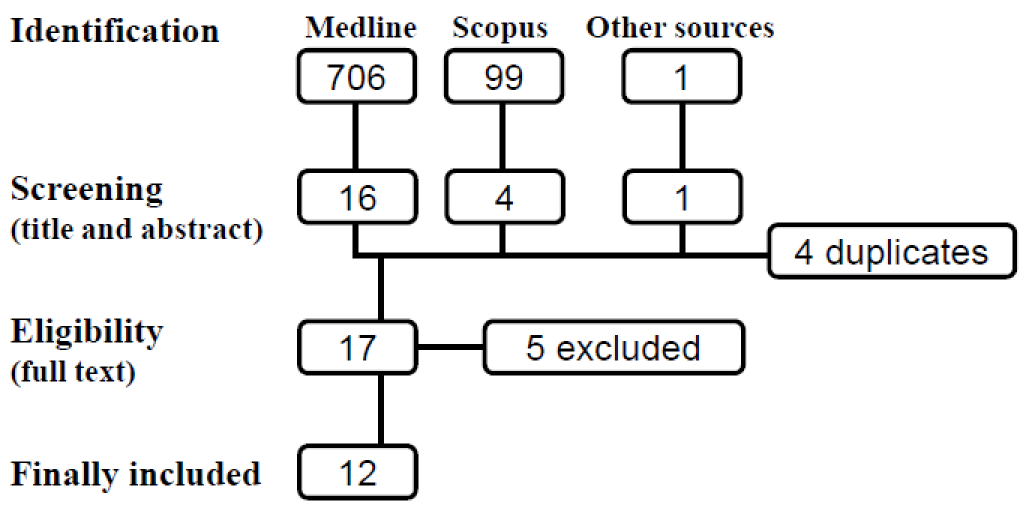
In the second approach, in order to obtain risks for a higher contrast of exposure, we calculated the interquartile range increase (i.e. the difference between the first and third quartiles of greenness) as a proxy of the highest vs. the lowest categories of exposure, which in each study might represent 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 further 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.

Because of the small number of studies included in each meta-analysis, we used random effect meta-analyses, even if the 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 (Figure 1).

Figure 1. Selection process of the article finally included.



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 diseases (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 diseases 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 fatalities mortality (Richardson et al. 2012), all respectively evaluated in only one study (Table 1).

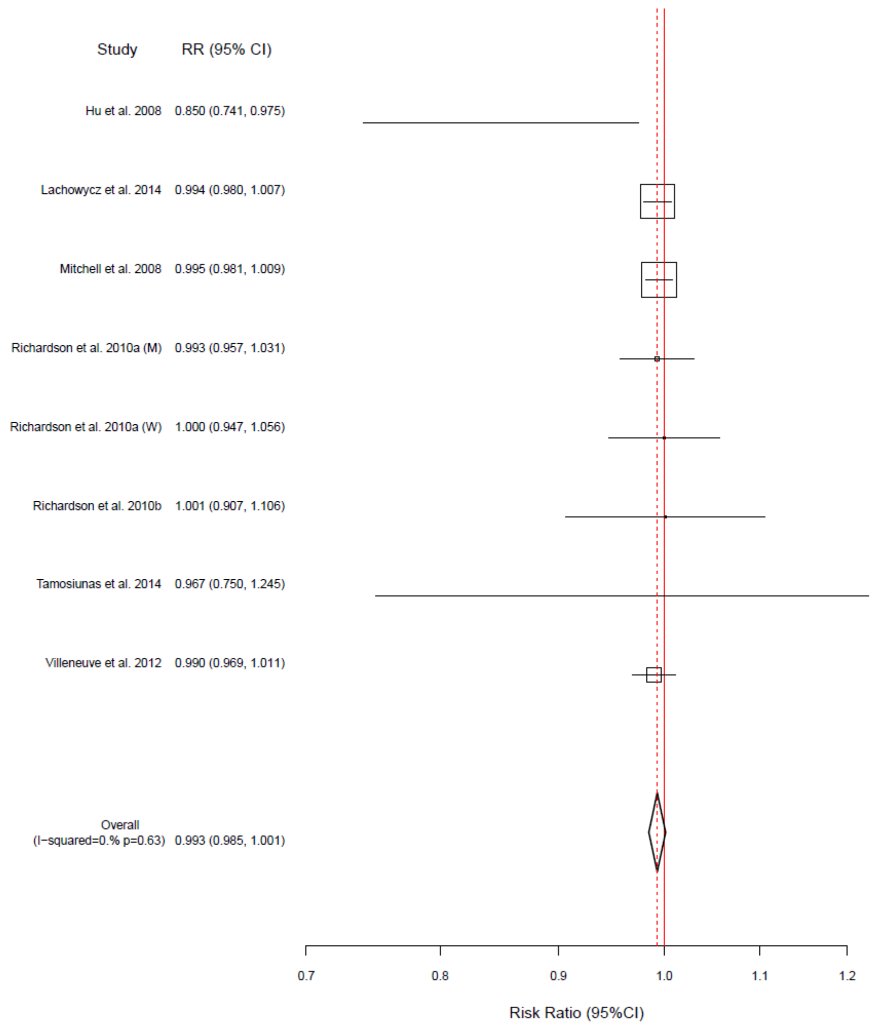
Results obtained in each study are summarized in Table 1. Overall, the risk of mortality from CVD was statistically significantly reduced in five of the eight studies evaluating the association between CVD mortality and residential greenness. These reductions were small, of less than 5%, in most of the 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 is 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).

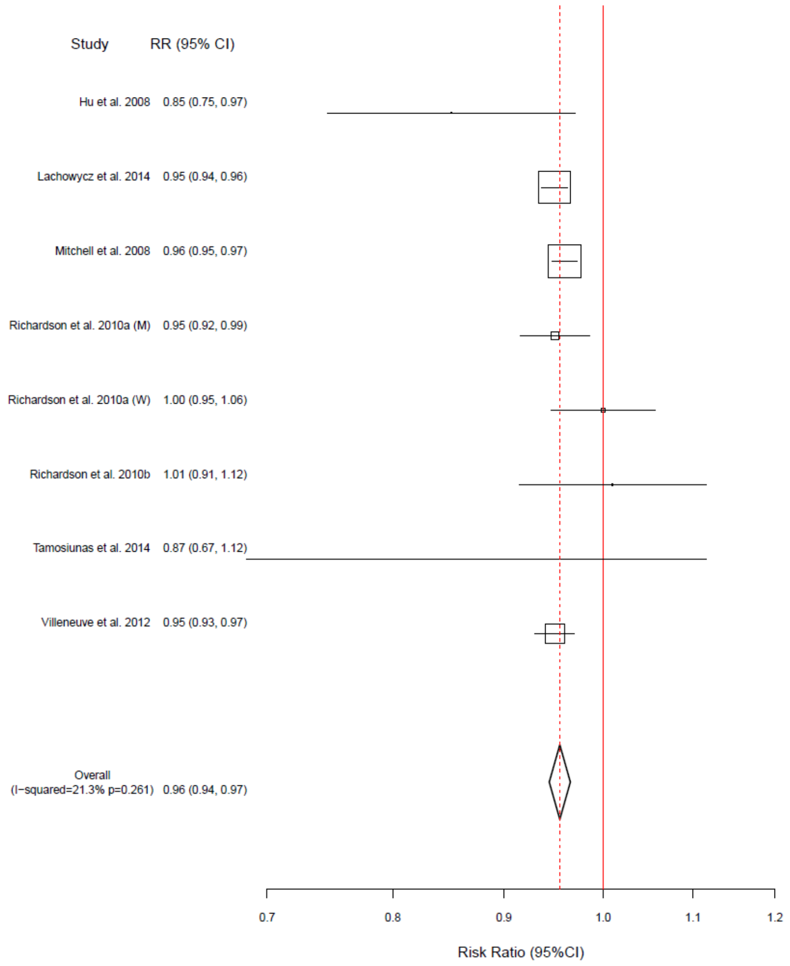
For each 10% increase of greenness there was a small and non-statistically significant reduction of the risk of CVD mortality [Risk Ratio (95%CI)= 0.993 (0.985, 1.001), p-het=0.63, Figure 2]. Results were similar for all-cause and lung cancer mortality, but the confidence intervals were wider (Supplemental 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, Figure 3 and Supplemental material, Figure C, respectively], however for lung cancer no association was observed (Supplemental material, Figure 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, Figures E-G).

Figure 2. Meta-analysis of the association between greenness and cardiovascular diseases (CVD) mortality for each 10% increase of greenness.



M (men), W (women)

Figure 3. Meta-analysis of the association between greenness (high vs low categories) and cardiovascular diseases (CVD) mortality.



M (men), W (women)

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 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. Jonkers *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 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 300m (Expert group on the urban environment 2001). This recommendation might be supported by the fact that 300-400m 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 to 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 conduction 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 percentatge of green space we observed similar results 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 CVD 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 (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.

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Supplemental material

Residential green spaces and mortality: a systematic review

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Table A. Characteristics of the studies on green spaces and mortality.

Author (year, country)	Study design	Statistical methods	Co-variables of adjustment and other relevant information	Quality (%)
Harlan et al. 2013, The USA	Ecological	Binomial regression models	Ethnicity, Latino immigrant, poverty, education, having air conditioner/cooler, age, living alone	50
Hu et al. 2008, The USA	Ecological	Poisson regression analysis	Buffer level: standardized (by age) stroke mortality rate, household income, air pollution	40
Lachowycz et al. 2014, The UK	Ecological	Negative binomial regression analysis	CAU level: Standardized (by age and sex) mortality, deprivation index, urban-rural classification, population density Analysis stratified by socio-economic status	40
Mitchell et al. 2008,The UK	Cross-sectional	Negative binomial regression analysis	Individual level: age at death, sex. CAU level: income deprivation index, education, living environment, population density, degree of urbanity. Sensitivity analysis with only urban areas Analysis stratified by socio-economic status	60
Mitchell et al. 2011, The UK	Cross-sectional	Negative binomial regression analysis	Individual level: age and sex CAU level: income deprivation, population density, air pollution Excluded external causes of mortality (e.g. car accident)	60
Richardson et al. 2010, The UK	Ecological	Negative binomial regression analysis	CAU level: counts of mortality by age-sex groups, income deprivation, air pollution, smoking rate Country Only urban wards Analysis stratified by gender	60
Richardson et al. 2010, New Zealand	Ecological	Negative binomial regression analysis	CAU level: counts of mortality by age-sex groups, income deprivation, air pollution, smoking rate Only urban wards	60
Richardson et al. 2012, The USA	Ecological	Linear regression analysis	49 big American cities included Only urban area included City level: Household income, % of non-Hispanic white population, air pollution, urban form and function	50
Tamosiunas et al. 2014, Lithuania	Cohort	Cox proportional hazards regression analysis	Parks had to be of at least 1ha and covered by trees by at least 65%, all provided recreation opportunities Participants lived at least 1y in their current address Individual level: age, sex, smoking, arterial hypertension, low physical activity, high total cholesterol and glucose, overweight/obesity, diabetis mellitus, low cognitive function, symptoms of depression, self-rated health, quality of life, use of parks	90
Uejio et al. 2011, The USA	Ecological	Generalizes linear and mixed models	CAU level: surface temperature (average, maximum), impervious surface, housing density, single family detached house, residents below the poverty line, household renting, population age 65 or older, people living alone, people with disabilities, linguistically isolated households, households with >7 residents, black, Hispanic, American Indian, Asian American, Residents changed household, vacant household, year house built, housing value	40
Villeneuve et al. 2012, Canada	Cohort	Cox proportional hazards regression analysis	Background rates stratified by age and city, rate ratios adjusted for individual-level covariates (income, age, sex and marital status), and census variables (income, unemployment, immigration), land-use regression estimates of NO_2 and distance to major roads and highways. Inclusion criteria: individuals at baseline ≥35 years and reside in one of the above 10 urban areas for at least one tax filing between 1982 and 1986.	80
Wilker et al. 2014, The USA	Cohort	Cox proportional hazards regression analysis	Population of stroke survivors Individual level: age, sex, race, Hispanic ethnicity, smoking status, history of stroke, coronary heart disease, atrial fibrillation, heart failure, diabetes, dyslipidemia, hypertension, school level, household income, distance to the major roadway	90

CAU: Census area unit

Table B. Criteria for quality assessment of the studies.

Study design	0 = ecological, 1 = cross-sectional, 2 = longitudinal
Confounding factors	0 = no confounding factors considered, 1 = confounding factors considered but some key confounders omitted, 2 = careful consideration of confounders
Statistics	0 = flaws in or inappropriate statistical testing or interpretation of statistical tests that may have affected results, 1 = appropriate statistical testing and interpretation of tests
Potential bias	0 = other study design or conduct issues that may have led to bias, 1 = no other serious study flaws
Multiplicity	0 = exposure of interest one of the many variables being tested, 1 = exposure of interest the main variable tested
Green exposure assessment	0 = expert assessment (audit), 1 = satellite system or land-cover map
Effect size	0 = incomplete information, 1 = complete information (estimate and standard error or confidence interval).
Participants have been living at least 1 year in the studied area	0 = no or not clearly specified, 1= yes

The highest total possible score is 10, which has been transformed into percentage (100%)

Figure A. Meta-analysis of the association between greenness and all-cause mortality for each 10% increase of greenness.

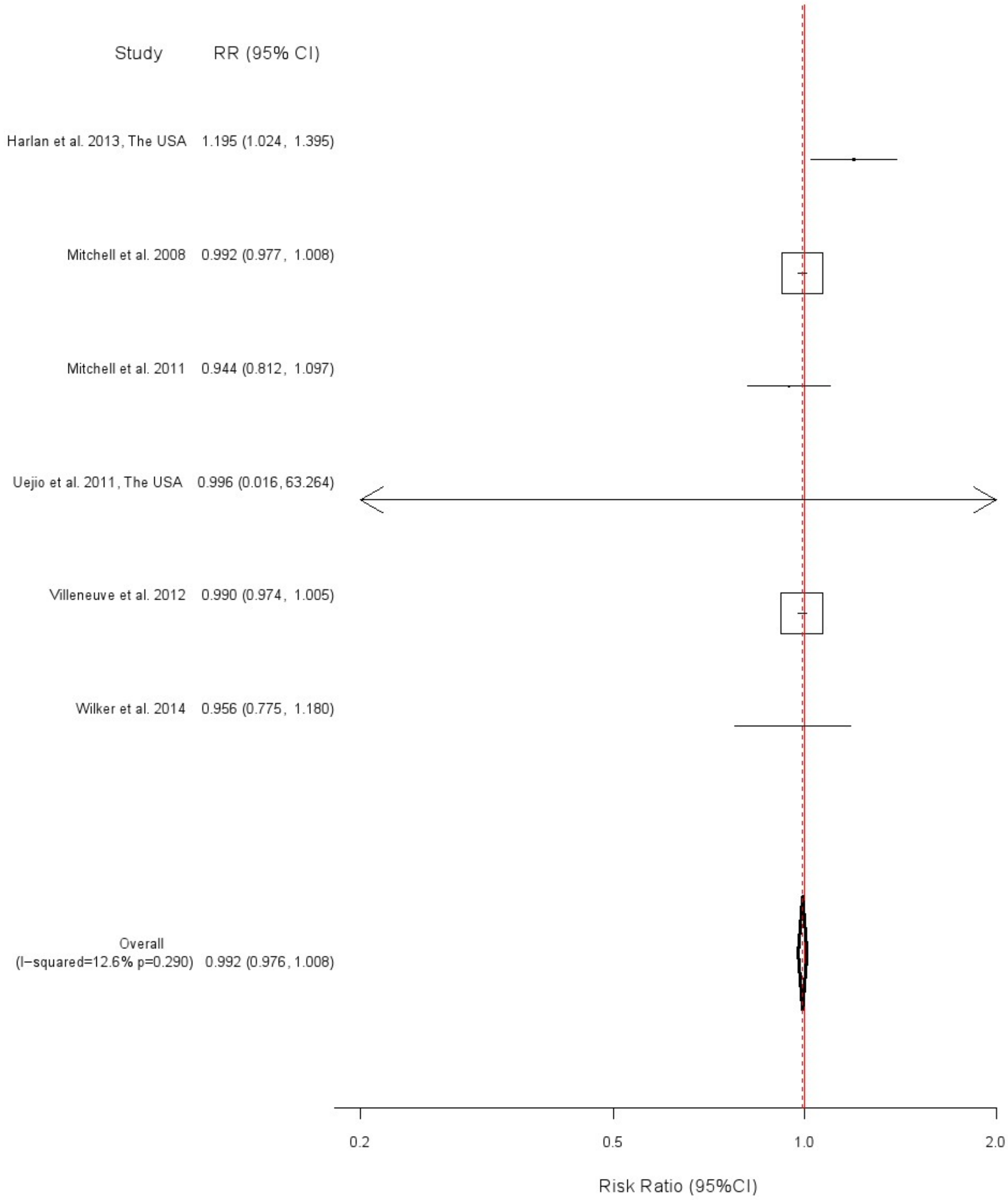
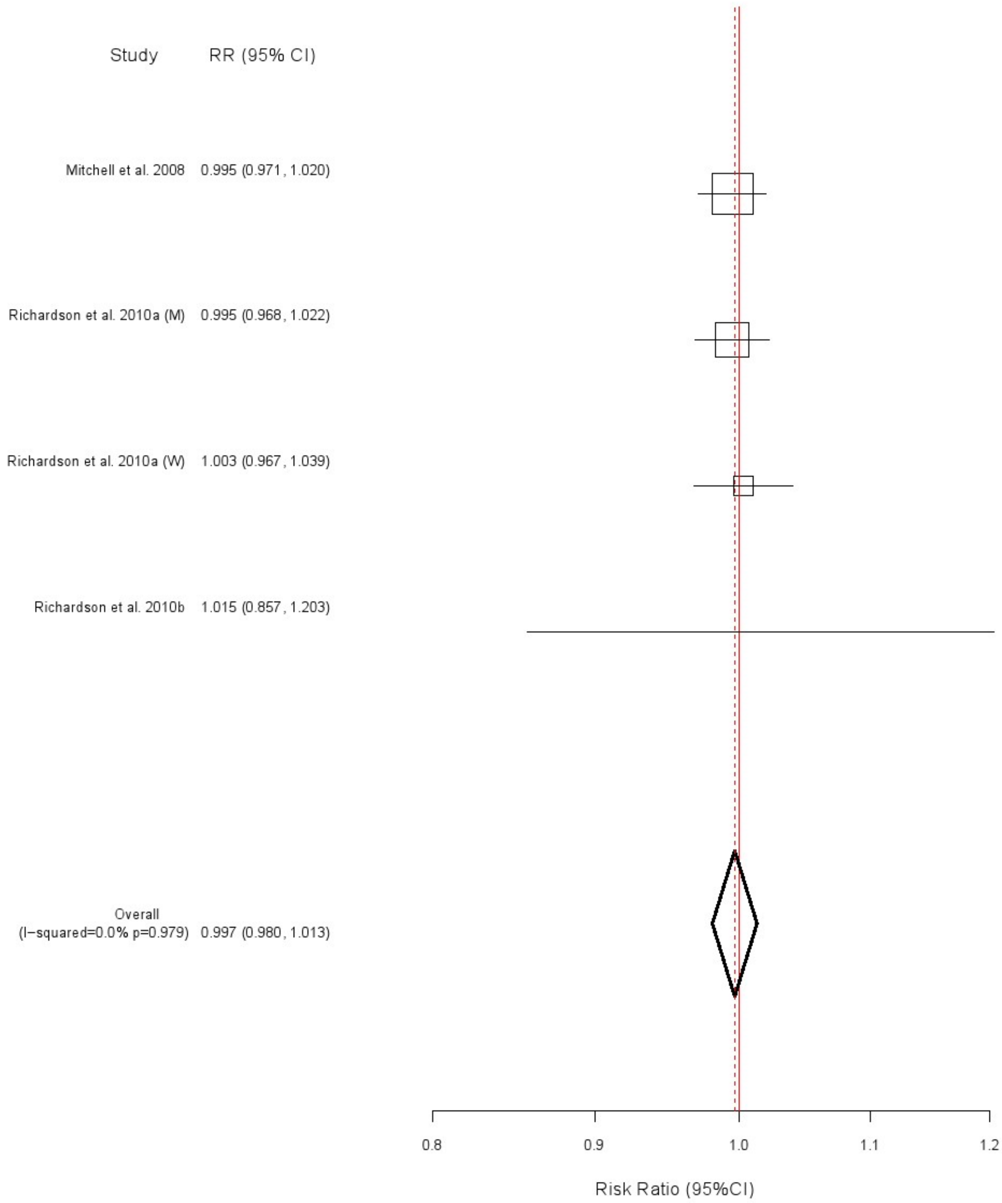


Figure B. Meta-analysis of the association between greenness and lung cancer mortality for each 10% increase of greenness.



M (men), W (women)

Figure C. Meta-analysis of the association between greenness (high vs low categories) and all-cause mortality.

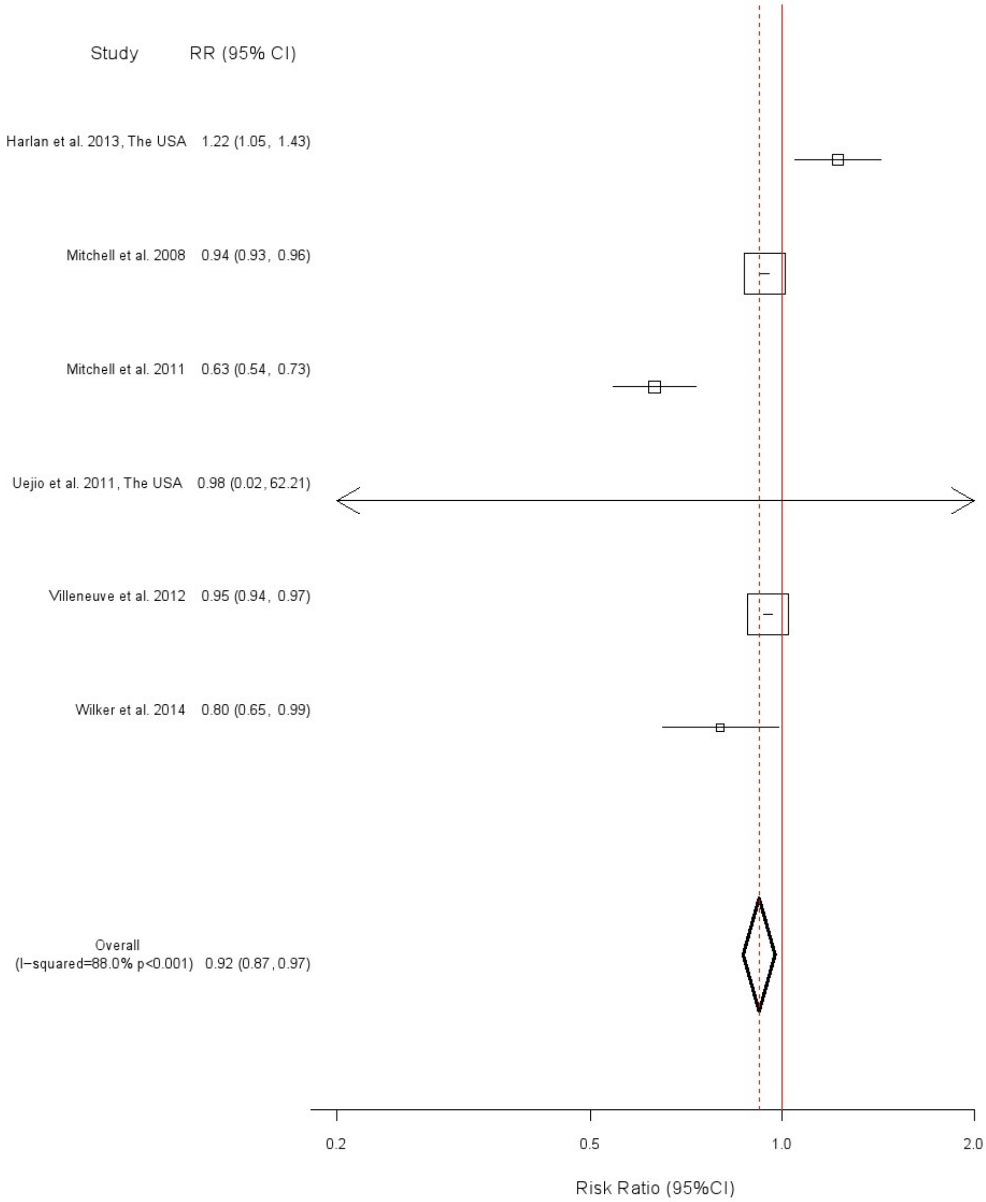


Figure D. Meta-analysis of the association between greenness (high vs low categories) and lung cancer mortality.

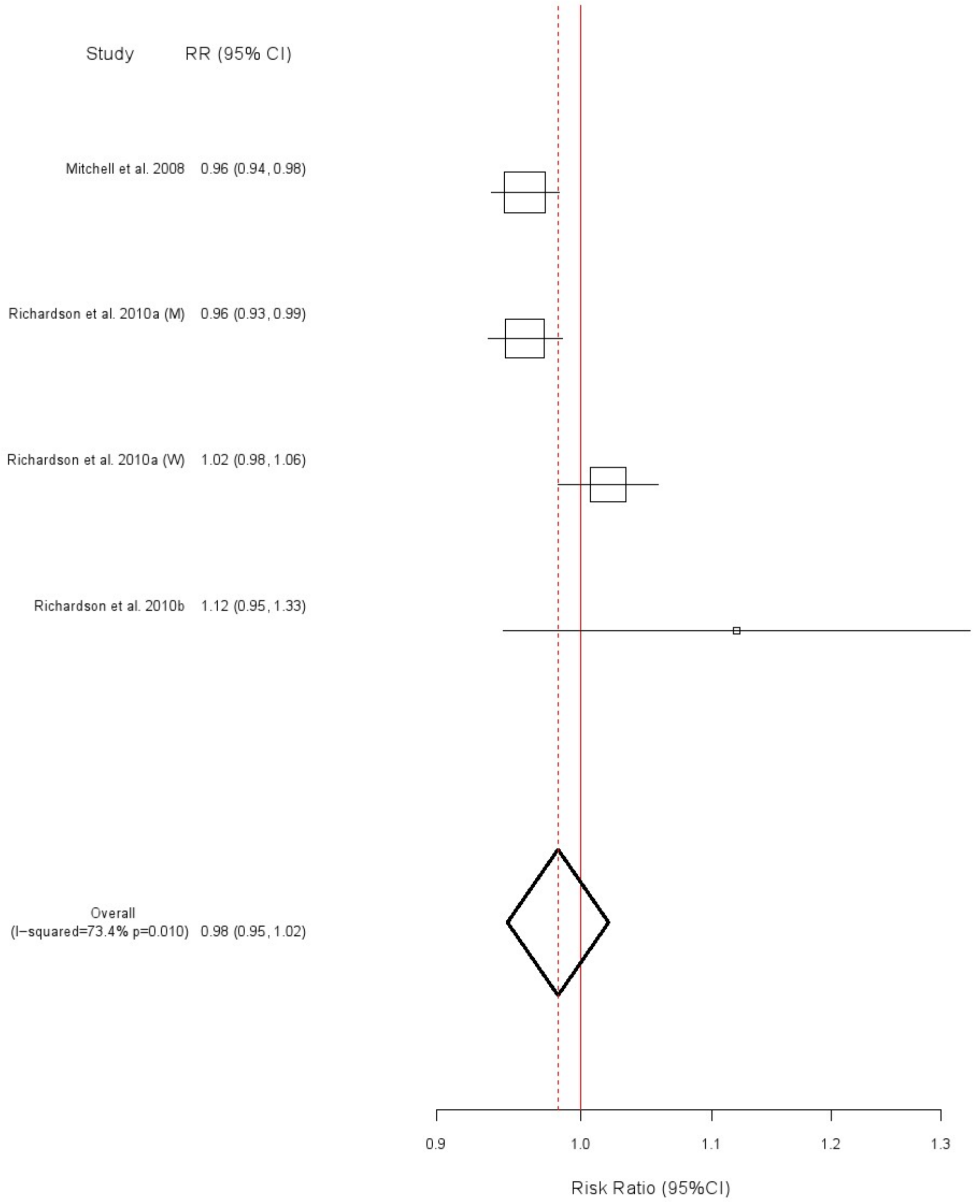
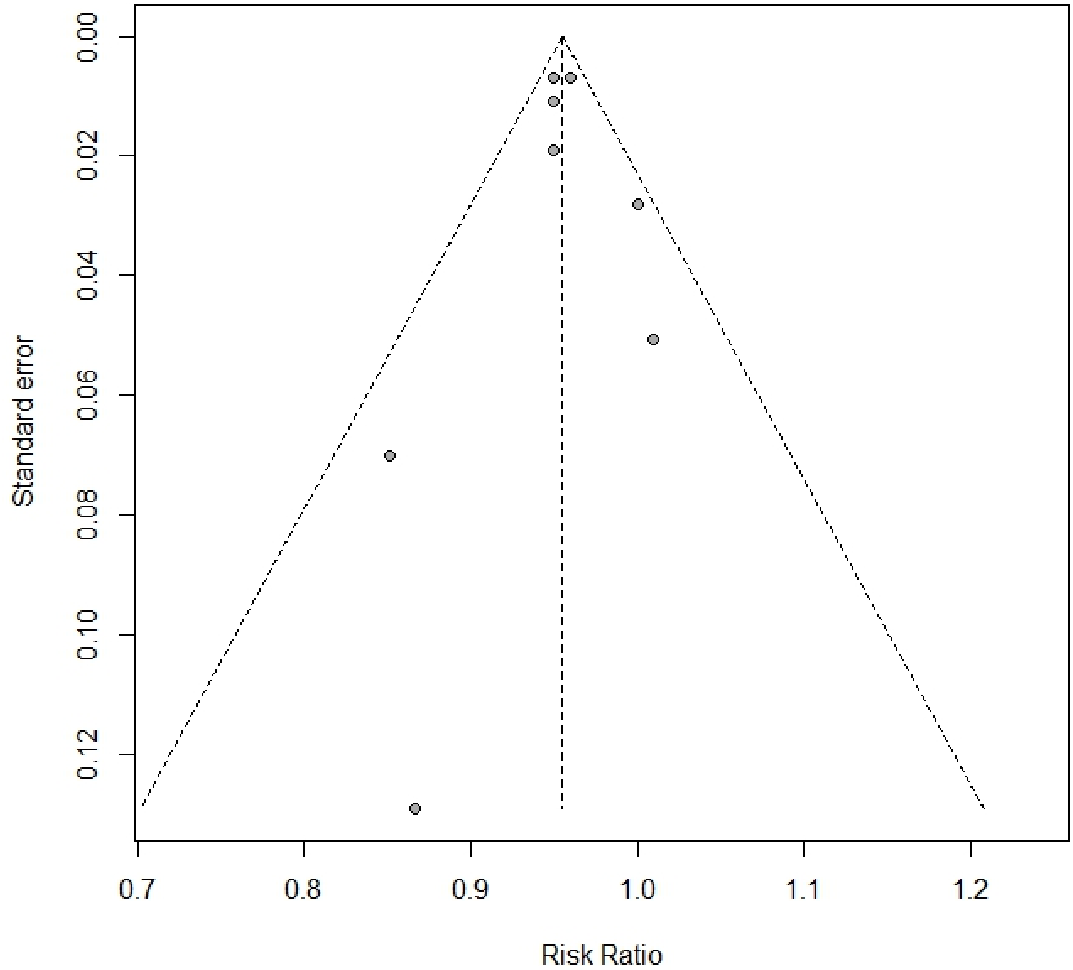


Table C. Sensitivity analyses for the association between surrounding greenness or access to green spaces and mortality excluding studies one by one.

	10% increase of greenness		High vs low categories of exposure	
	Risk ratio (95%CI)	**p-heterogeneity**	**Risk ratio (95%CI)**	**p-heterogeneity**
All-cause mortality				
All studies included	0.992 (0.976, 1.008)	0.29	0.92 (0.87, 0.97)	<0.001
Excluding Harlan et al. 2013	0.991 (0.980, 1.002)	0.97	0.90 (0.85, 0.95)	<0.001
Excluding Mitchell et al. 2008	1.010 (0.936, 1.089)	0.19	0.88 (0.70, 1.10)	<0.001
Excluding Mitchell et al. 2011	0.993 (0.975, 1.012)	0.22	0.95 (0.92, 0.99)	0.01
Excluding Ueijo et al. 201	0.993 (0.974, 1.012)	0.19	0.92 (0.87, 0.97)	<0.001
Excluding Villeneuve et al. 2012	1.011 (0.938, 1.089)	0.19	0.88 (0.70, 1.09)	<0.001
Excluding Wilker et al. 2014	0.993 (0.974, 1.012)	0.20	0.93 (0.88, 0.98)	<0.001
Cardiovascular diseases (CVD) mortality				
All studies included	0.993 (0.985, 1.001)	0.63	0.96 (0.94, 0.97)	0.26
Excluding Hu et al. 2008	0.994 (0.985, 1.002)	1.00	0.96 (0.95, 0.96)	0.43
Excluding Lachowycz et al. 2014	0.993 (0.982, 1.003)	0.51	0.96 (0.94, 0.97)	0.24
Excluding Mitchell et al. 2008	0.992 (0.981, 1.003)	0.53	0.95 (0.94, 0.97)	0.25
Excluding Richardson et al. 2010 (M)	0.993 (0.985, 1.002)	0.51	0.96 (0.94, 0.97)	0.18
Excluding Richardson et al. 2010 (W)	0.993 (0.985, 1.001)	0.52	0.95 (0.95, 0.96)	0.41
Excluding Richardson et al. 2010	0.993 (0.985, 1.001)	0.52	0.95 (0.94, 0.96)	0.27
Excluding Tamosiunas et al. 2014	0.993 (0.985, 1.001)	0.52	0.95 (0.94, 0.97)	0.22
Excluding Villeneuve et al. 2012	0.994 (0.985, 1.003)	0.53	0.96 (0.94, 0.97)	0.20
Lung cancer mortality				
All studies included	0.997 (0.980, 1.013)	0.98	0.98 (0.95, 1.02)	0.01
Excluding Mitchell et al. 2008	0.998 (0.977, 1.019)	0.92	1.00 (0.94, 1.06)	0.01
Excluding Richardson et al. 2010 (M)	0.998 (0.978, 1.018)	0.92	1.00 (0.94, 1.06)	0.01
Excluding Richardson et al. 2010 (W)	0.995 (0.977, 1.013)	0.97	0.96 (0.94, 0.98)	0.21
Excluding Richardson et al. 2010	0.996 (0.980, 1.013)	0.93	0.98 (0.94, 1.01)	0.01

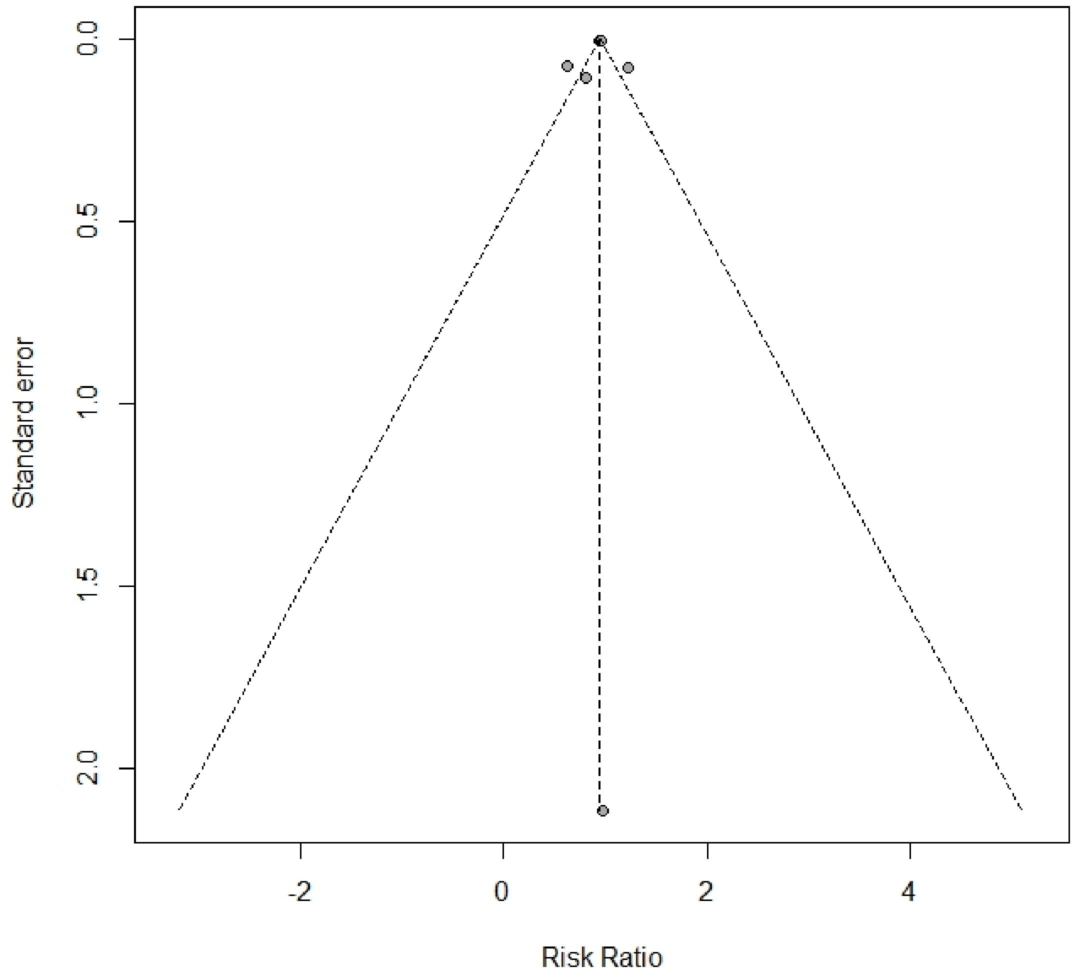
Random-effect models
M (men), W (women)

Figure E. Funnel plot for studies evaluating cardiovascular diseases (CVD) mortality



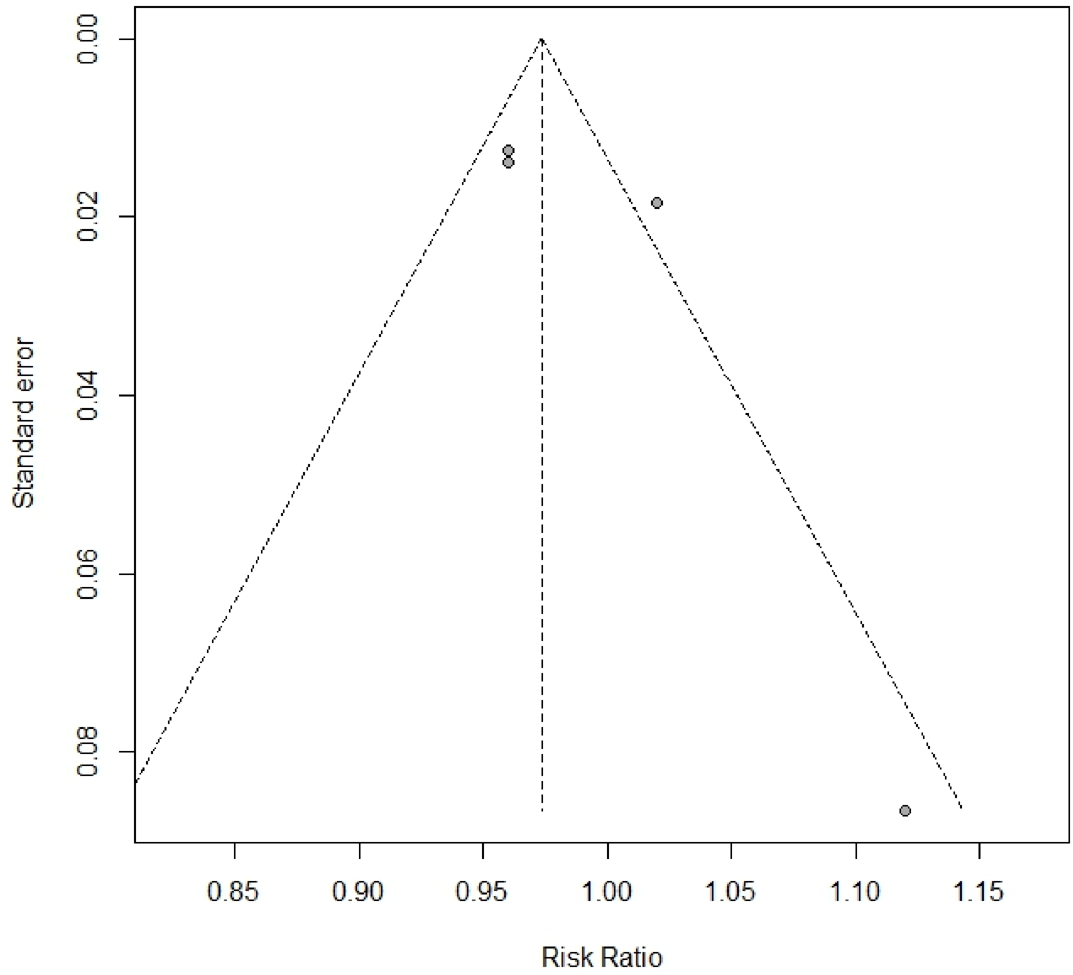
Egger test: 0.94

Figure F. Funnel plot for studies evaluating all-cause mortality



Egger test: 0.29

Figure G. Funnel plot for studies evaluating lung cancer mortality



Egger test: 0.76

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