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Narrative review

Mitigation of air pollution by greenness: A narrative review

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ABSTRACT

Air pollution represents one of the world's most important environmental health risks, being associated with an increased rate of multiple diseases (mainly cardiopulmonary) and of premature deaths. A number of actions have been suggested and implemented to mitigate the deleterious health effects of air pollution. Accordingly, recent research has attempted to estimate the beneficial effect of exposure to greenness on human health. In this narrative review, we summarize and review the current literature on the favourable association between greenness and human health in both the outdoor and indoor environments. The potential mechanisms underlying this benefit will be also addressed.

1. Introduction

Air pollution has a number of detrimental effects on human health and is considered a major threat for both adults and children [1–8]. The World Health Organization (WHO) estimated that one of nine deaths is the result of air pollution-related conditions [9]. The Global Burden of Disease report [10] identified air pollution among the leading risk factors for disease burden, being globally responsible alone for 3.1% of all Disability-Adjusted Life Years (DALYs). Air pollution represents one of the world's largest avoidable causes of premature deaths, mostly caused by ischemic heart disease, stroke and chronic obstructive pulmonary disease [11]. In addition, according to the International Agency for Research on Cancer, air pollution has become the most widespread environmental carcinogen [12]. If acute and long-term exposure to ambient air pollution represents a serious threat for health in western industrialized countries, the burden of this problem is even higher in low-income countries (especially in the Asian continent). In them population explosion along with widespread industrialization coupled with urbanization resulted in dense urban centers with poor quality of ambient air [7, 13, 14], and also high concentrations of indoor air pollution due to the use as energy sources of biomass fuels (coal, wood and other solid fuels) [15–17]. Accordingly, household air pollution has become a serious threat for health and is estimated to be one of the top five major risk factors for the global burden of diseases (4.3% of global DALYs), accounting for 3.9 million premature deaths in 2010 [15].

A number of policies have been addressed and implemented by local governments and international authorities in order to reduce air pollution and related climate changes, the mitigation actions being directed mainly towards the areas of transport, urban planning, power generation and industry [18, 19]. Because there is increasing interest in the potential benefit of greenness in reducing the deleterious effects on health of outdoor and indoor air pollution [20], the current knowledge on how plants may be able to mitigate air pollution will be summarized in this narrative review.

2. Search methods

We performed an electronic search on PubMed using the following terms without time limits: “ambient air pollution”, “outdoor”, “indoor”, “particulate matter”, “PM”, “air pollutants”, “mortality”, “human health”, “health effects”, “green space”, “greenness”, “plants”, “mitigation”, “exposure”, “natural environment”, “residential” and “vegetation”. The date of the last search was March 31, 2018. The bibliographic references of all retrieved original articles and reviews were assessed for additional relevant articles. We also reviewed recent research on the relationship between greenness and human health from non-biomedical journals, as well from state environmental and health agency regulatory documents.

3. Outdoor air pollution

Outdoor air pollution is a mixture of thousands of components. The most important from a health perspective are particulate matter (PM), volatile organic compounds (benzene, toluene, ethylbenzene, xylene, formaldeide) and inorganic pollutants (ozone [O_3], nitrogen dioxide [NO_2], carbon monoxide [CO] and sulphur dioxide [SO_2]). Primary

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pollutants, such as soot particles and oxides of nitrogen and sulphur, are emitted directly into the air by the combustion of fossil fuels [21]. Major sources of primary particles include motorized road traffic, power generation, industrial sources and residential heating. Secondary pollutants, formed when primary pollutants react or interact in the atmosphere, include mainly ozone (O_3) and PM, which is classified, on the basis of the size of its particles, in coarse (diameter < 10 μm; PM_{10}), fine (diameter < 2.5 μm; $PM_{2.5}$) and ultrafine (< 0.1 μm; $PM_{0.1}$) [22]. Resuspension of soil and road dust by wind or moving vehicles, as well as construction work and industrial emissions, results in coarse particles (PM_{10}). Fine particles are derived primarily and directly from direct emissions from combustion processes, such as gasoline and diesel fuel, wood burning, coal burning for power generation and industrial processes. Ultrafine particles are fresh emissions from combustion-related sources, such as vehicle exhaust and atmospheric photochemical reactions, and are recognized to be important markers of exposure to traffic exhaust along main roads [23]. Fine and ultrafine particles are those with the worst effects on health, because they can reach the deepest portions of the airways or even the blood stream directly [23, 24].

A number of studies analyzed the relationship between the capacity of the natural environment to buffer exposure to air pollution and its consequences on human health [25]. In particular, greenness protects individuals from air pollution by removing a number of pollutants, especially PM, O_3, CO, CO_2, SO_2 and NO_2 [26]. For instance, the capacity of removal of excessive atmospheric CO_2 produced from industries by a plant during its life cycle is remarkable, ranging from 0.5 to 6 tons, and depends on the enzymatic system specific for each vegetal species [27]. Thus the potency of air pollution mitigation greatly varies from one vegetal species to another, and plants suitable for a peculiar urban area should be chosen according to the types of main air pollutants present and to be removed in that area [28]. In this respect, data coming from an ecological study in Barcelona, Spain are very impressive. In 2008, trees and shrubs removed in Barcelona 305.6 tons of pollutants (166 tons of PM_{10}, 73 tons of O_3, 55 tons of NO_2, 7 tons of SO_2 and 6 tons of CO), a service with monetary value to society estimated at 1.1 million euros [27]. A greater degree of air pollution removal was calculated by Novak and colleagues in 2006 in other urban areas (Baltimore, Washington and Minneapolis) in the USA [29]. Table 1 classifies the vegetal species according to their capacity of removal of ambient air pollutants.

The positive impact of greenness on health has been recently outlined in a randomized crossover study, which showed that the beneficial effect on cardiopulmonary function of a walking exercise observed in an urban green space was lost when it was done in a traffic-polluted road [30]. However, besides the reduction of air pollution, greenness is likely to benefit health through multiple additional mechanisms, i.e. by lowering exposure to extreme heat and noise, increasing opportunities for physical activity, providing a location for social engagement and decreasing psychological stress and depression through direct contacts with nature [31–33] (Fig. 1). Importantly, a prospective study conducted by James and colleagues on 108,630 women in USA showed that higher levels of greenness around each participant's home were associated with a 12% lower rate of overall mortality, and that this association was the strongest for cancer and respiratory mortality [34]. These findings are consistent with those of another study conducted by Mitchell and Popham in England that observed lower levels of all-cause and cardiovascular mortality in the greenest areas, with an estimated 6% reduction (95% CI: 4%–7%) in all-cause mortality in geographic units endowed with the highest quintile of green space [35]. In addition, a recent systematic review and meta-analysis by Gascon and colleagues evaluating 12 studies found evidence of a reduction of the risk of cardiovascular mortality in areas with higher residential greenness [36]. With respect to cancer risk, a case-control study conducted in Montreal, Canada showed that men living in greener areas had lower risks of prostate cancer, independently of socio-demographic and lifestyle factors [37]. In addition, the association between exposure to greenness with skin [38], lung [39–41] and esophageal cancers has been established [42]. Wilker and colleagues followed patients in Boston, Massachusetts area who had suffered from ischemic stroke and found that those living in the highest quartile of the Normalized Difference Vegetation Index (NDVI, measured using satellite imagery) had an estimated 22% (95% CI: 3%–37%) lower rate of all-cause mortality than those in the lowest quartile [43]. Similarly, a recent analysis of greenness and mortality in residents of Ontario, Canada found that greater exposure to greenness was associated with higher survival rates [44].

Recent investigations have also indicated the potential positive relationship between greenness exposure, maternal health and birth outcomes [45–49]. In a study conducted by Ebisu and colleagues [47] in babies born in the USA, a greater proportion of park land near residence was associated with 7.6% lower risk of low birth weight. This finding is consistent with other studies. For instance, two studies conducted in Tel Aviv, Israel and Munich, Germany found positive associations between green space and birth weight [50, 51]. Residential greenness decreased the likelihood of a child being small for gestational age in Portland, Oregon and in Vancouver, Canada [52, 53]. Studies linking greenness with maternal health outcomes gave less consistent results [45]. One of them found a relationship between more greenness and reduced odds of preeclampsia [54], but another study failed to find a such an association [55].

All in all, positive associations between outdoor greenness and various health outcomes were rather consistently identified across the majority of studies.

Table 1
Classification of vegetal species according to their capacity of removal of outdoor air pollution removal.

Mitigation effect[a]	Species
Excellent	Elm tree, common ash, wild lime tree, verrucous birch, curly maple, hackberry
Good	White hornbeam, country maple, cherry tree, tulip tree, laurel, whitethorn, photinia red robin, apple tree
Medium	Elder, mulberry crying, Judas tree

From: http://www.es.lancs.ac.uk/cnhgroup/iso-emissions.pdf

[a] Calculated considering the effect on remove air pollutants removal and ozone generation.

4. Indoor air pollution

According to the aforementioned WHO report [9], about 7 million people die each year owing to air pollution and about half of these deaths are due to indoor air pollution. The US Environmental Protection Agency (EPA) has ranked indoor air pollution as one of the topmost five threats to human health [56]. Because people spend indoor, in the workplaces or at their homes, 70–90% of their times, they are exposed to the harmful emissions from the synthetic material used in the construction, from tools and instruments, as well as to volatile inorganic and organic compounds [57]. Pertaining to the latter pollutants, examples with particularly adverse effects on human health include benzene, toluene, xylene, styrene, ammonia, formaldehyde and acetone. Bio effluents such as acetone, methane and ammonia are also contributing to indoor pollution. Their deleterious effects may range from acute symptoms (mostly allergic or from irritation of mucosal airways) to long-term consequences (mainly cancers and cardiopulmonary disorders) [58]. Indoor air pollution is also thought to cause the so called Sick Building Syndrome, a disorder characterized by mucosal, skin and general symptoms which typically affects individuals that work in offices with higher levels of indoor air pollutants [57, 59]. For instance, in a recent study by Logue and colleagues [60], the indoor residential concentrations of volatile organic compounds were