Maximizing the Benefits of Green Spaces for Urban Communities

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Urbanization may elicit thoughts of concrete jungles, skyscrapers, and busy vehicle traffic. For a long time, this has been the standard for urban cities, but as climate change continues to affect natural resources, built structures, and public health, cities are looking at implementing green spaces into urban areas to reduce air pollution. Green spaces are places in urban areas with grass or another type of vegetation such as trees (Oxford Languages, 2023). Green spaces can provide a multitude of benefits such as absorbing air pollutants (EPA, 2023), providing physical and social health benefits (Larson et al., 2016), and protecting against extreme weather events. For example, green spaces can help with the absorption of water and mitigate flooding events, or provide shade to cool cities facing extreme heat days (Opperman, 2014 & Santamouris, 2014). Green spaces can also be implemented as a barrier between air pollution and people through vegetated buffers (United States Environmental Protection Agency [EPA], 2022a). Vegetated buffers reduce ambient air pollution through absorption rather than only redirecting it to other areas (Pettit, 2021).

With a growing interest from governments and advocacy groups in implementing green spaces and vegetated buffers, more attention is being given to the lack of green spaces that environmental justice communities face and how this issue could be affecting their health. Due to redlining, communities of color were historically sold land that was in poorer conditions than what white communities were able to obtain (Cimons, 2020). This in turn led to a lack of investment in these areas by the government and investors. A lack of investment meant that communities of color had and still have less access to beneficial environmental features (Cimons, 2020). The majority of people living in urban areas are non-white communities of color (Parker et al., 2018). On the other hand, areas that have predominantly white populations tend to have on average more parks, green spaces, and built environment amenities than communities of color (Kephart, 2022). The built environment is a human-made feature (or lack of) in the environments where people live, work, and play (EPA, 2022b).

A compounding problem that communities of color face in addition to lacking green space is that they are exposed to higher concentrations of air pollution in their environments than white populations (EPA, 2022c). This unequal distribution of air pollution concentrations can lead to higher health burdens due to poor air quality (EPA, 2022c). According to Tessum et al. (2021), this phenomenon where communities of color, or non-white groups, face higher exposures to air pollution holds true across different regions and income levels. One might think that higher income individuals could escape this exposure by moving out of areas but we see that this is simply not the case. This points to an environmental justice issue since race plays a role in the concentrations of air pollution that people are being exposed to in their environments.

Accordingly, one solution that has been proposed for environmental justice communities is implementing green spaces into urban areas to reduce air pollution and provide additional benefits of green space for these areas. Although it is known that green space can reduce air pollution (EPA, 2023), research gaps exist for the effects of green spaces in urban areas (Kondo et al., 2018). Given that urban green spaces are a fairly new intervention, the effects on urban populations is also not well-known. There is also a lack of guidance for communities around selecting green spaces that reduce their problem pollutants, though these features are important in maximizing the benefits of green spaces for public health benefits (Knight et al., 2021).

Research Questions

The first research question that will be answered is which ambient air pollutants and how much can be reduced through different types of green spaces and which cannot? Ambient air pollution refers to outdoor air pollution World Health Organization [WHO], 2022). Once an air pollutant of interest is identified, where should green spaces be placed in urban spaces to maximize benefits to the people living there?

The goal of this review is to compile the most current research on these topics so that communities of color or organizations supporting these communities can advocate for equitable green space investments as a way to reduce air pollution concentrations. According to Bikomeye et al. (2021), taking an equitable approach in green space investments would benefit communities of color by improving their health outcomes and resources. Equity in this review means committing to reduce and thereby eliminate unfair practices (Braveman et al., 2011).

Methods

A search query was performed on the PubMed database to find articles related to green space and air pollution. The queried search term was “((air pollution AND green space) AND (urban areas))” and was filtered by articles published between 2018-2023, in English, and studying humans. The search resulted in 54 articles. The titles of these articles were reviewed for relevance to the research questions. Seven articles were selected for further review which resulted in a total of nine of those articles being used in this review. Another search query was performed using “effect of green space on air pollutant” using the same filters as the first query, which resulted in 102 articles. Of these, many of the same articles from the first search appeared. Five additional articles were selected with this search term and were reviewed for relevance. In addition to the database specific search, articles by Christina H. Fuller were searched for relevance to the question. Dr. Fuller had three articles about green space which will be used in this review to answer the research questions. A snowball search of the gathered articles by Dr. Fuller resulted in further articles related to the questions of interest.

Additionally, a broader search query was performed in the UC Library Search and filters included years: 2018-2024, source: articles, and language: English. Queried search terms included “air pollution AND green space,” “green roofs and air pollution,” “green space as an air pollution control in urban areas,” “effects of trees on air pollution,” “Green space reduction on air pollution,” and “using green space to reduce air pollution.” This search resulted in over 110,000, 31,0000, 89,000, 78,000, and 72,000 results for each query respectively. The titles of the first 50 articles from each search query were reviewed for relevance to the research question. Relevancy was determined by titles that addressed both green spaces or buffer zones, and air pollution. The most recent literature from this search was prioritized in the final selection, though snowballed literature may be older.

Results

Effects of Green Spaces on Air Pollutants

Given that the built environment affects the air pollutant concentrations and ability of green space to reduce these, certain international areas may share similar built environment characteristics to areas in the US. Air pollutants including particulate matter PM2.5, PM10, and carbon monoxide (CO) were all significantly lower in countries with high amounts of green spaces compared to those with low amounts (Meo et al., 2021). Levels of green space were determined using the Environmental Performance Index (EPI). Countries across different income levels were compared and their mean scores were used to compare amounts of pollutants. These relationships will be explored further with the goal of generalizing results to the US.

Carbon monoxide was used as a measure of air pollution in an exposure study for students that walked to school (Amorim et al., 2013). Carbon monoxide is one type of air pollutant that is in the air we breathe in. Amorim et al. (2013) found that carbon monoxide exposure was usually reduced near trees but not always. Since they only used carbon monoxide to measure air pollution, it is possible that associations could be different with a different air pollutant. Two important factors that were mentioned were individual tree features like leaf thickness and wind speeds. Wind speeds are also affected by the trees themselves since the trees' features can slow these speeds down. Where wind speeds are slowed down, air pollution hotspots might form instead of dispersing; This is dependent on the layout of streets and weather conditions that are typical in the area. Gallagher et al. (2015) also found that the layouts of streets, weather conditions, and height of green spaces used were important in determining how much air pollutants were absorbed.

Another study looked at the effects of vegetated buffers on particulate matter and black carbon pollutants. Particulate matter are small particles that pollute the air and are typically described by their sizes (EPA, 2022e). Fuller et al. (2017) looked at the effects that a vegetated buffer of trees near roads had on air pollutant concentrations of total particulate matter numbers and black carbon (BC). They found that reductions were consistent for black carbon across different seasons of the year when other factors were not taken into account. Reductions in particulate matter were not consistent. When they took into account factors like weather and times of day, there were no clear reductions for both black carbon and total particulate numbers. It is possible that these other factors could be confounders to the air pollutants and will need to be accounted for when evaluating the effectiveness of the vegetated buffers.

Particulate matter was also explored by Almeida et al. (2020) along with nitrogen dioxide (NO2). They found that PM10 and NO2 concentrations were lower in a park with lots of vegetation compared to near roads. One caveat that was mentioned by the authors is that in areas with lots of NO_2 and dependent on weather conditions, certain trees can actually increase ozone (O_3). Ozone is one type of air pollutant that is considered a secondary air pollutant since it is formed by the combination of multiple air pollutants (EPA, 2022f). Certain trees might also release volatile organic compounds (VOC) that contribute to the formation of ozone, but more research is needed into specific species of trees. Volatile organic compounds are chemical compounds with "high vapor pressure" and do not dissolve in water easily (EPA, 2022g).

Maximizing Green Space Benefits

The amount of greenspace present is likely to affect how much air pollution is reduced. Logically, having more plants that can absorb and reduce pollutants could be expected to reduce overall pollution. Several studies found that higher vegetation led to increased reductions in pollutants. These studies looked at gardens, urban parks, and in more general terms green spaces.

In Brazil, Junior et al. (2022) found that higher vegetative cover in green spaces resulted in lower $PM_{2.5}$ concentrations than areas that had lower vegetative cover. A tunnel and garden in close proximity to one another in Rio De Janeiro were compared for the study. Because the areas were in such close proximity to one another, the reduction in $PM_{2.5}$ in the area with more vegetation, or plants, was attributed to the larger amount of green space.

In another part of the world, Delhi, India, Mueller et al. (2022) found that larger green spaces might be more beneficial than smaller areas of green space. They looked at exposure to air pollution of adolescents while walking in Delhi, India. To measure green space, they looked at different features including the Normalised Difference Vegetation Index (NDVI). The NDVI is used to determine the amount of vegetation density and view the greenness of an area (United States Geological Survey, n.d.). Mueller et al. (2022) took a geospatial approach in mapping out other green space characteristics of the area such as the number of trees, parks, forests, and how much green land was nearby.

One study quantified what constituted larger amounts of green spaces. Qiu et al. (2019) found that significant reductions in PM_{10} and $PM_{2.5}$ concentrations were present when urban green spaces had vegetative covers of 75% or more. With less percentage of vegetative cover, air pollutants studied were not reduced as much. Weather conditions, human activities, and seasons of the year were also important factors when looking at reductions in air pollution. Lastly, the openness of areas also contributed to how much air pollution was reduced. In closed spaces, trees and other plant types were more important than in open spaces where these specifics did not affect reductions in air pollutants as much. This is because in closed spaces, it is important to consider which plants might form pollution hotpots or trap them closer to the ground.

Vegetated Buffers and Trees

Trees may be used as a vegetated buffers near roads, in parks, and for residences. Xing et al. (2019) applied their findings of what trees were most efficient at removing air pollution in the form of PM2.5 to vegetated buffers. Using the ENVI-MET tool, they determined which tree characteristics could be most effective in different settings. Dense tree species with a low crown base were most effective at removing air pollution when placed 15 meters apart in width and used as a vegetated buffer near roads. These trees acted like a solid surface and blocked pollution. Planting rows of medium height trees with a low crown base and that don't have as much shade coverage were cautioned against; This is because these types of trees can trap pollution into one area. These types of trees were not recommended in the outer parts of parks.

Similarly, Tomson et al. (2021) said trees in street canyons are generally not recommended since they could contribute to pockets of air pollution forming, but they could be used in street canyons that are shallow. The recommended trees for these shallow street canyons would be trees with light crowns and trees should be spread out. Tomson et al. (2021) instead recommend a vegetated buffer of hedges with a thickness of at least 1.5 meters and height of 2 meters to block exposures from air pollution. Hedges like these are useful if there is a walking trail or path nearby that people are using. Again, characteristics of the plants selected and weather were important features in how much different air pollutants were reduced.

Urban trees, which are one type of green space, can remove "hundreds to thousands" of air pollutants including ozone (O3), sulfur dioxide (SO2), PM10, NO2, and CO in cities in the US (Nowak et al., 2006). Increasing the amount of trees that cover areas could lead to more significant removal of pollutants. Some key findings were that mixing tree heights can be less beneficial for pollution removal and areas that typically had less rain may benefit from larger increases in pollution removal. On the other hand, trees that are too tall could trap vehicle pollution which is usually closer to the ground. In areas with more air pollutants, reductions of air pollution by trees could be seen more.

Since effectiveness of vegetated barriers and interventions will be dependent on local conditions and species of vegetation selected, Hashad et al. (2021) used five different types of modeling to simulate the effects of different plant species on air pollutants. Air pollutants of interest were those that came from traffic sources. Information that was needed for this type of modeling included width and height of vegetation, leaf areas, wind speeds, and the size of the particle pollutant of interest. Leaf area measurements included the leaf area index (LAI) and density (LAD). Of the plant features that were used for modeling, width and height was most important along with the size of particles for determining how much air pollution could be reduced. The amount of traffic in an area, built environment, and wind were all noted as being important to determine effectiveness but were not included in the modeling. A combination of interventions such as implementing vegetated buffers and solid barriers like walls might be most effective in reducing air pollution according to Gallagher et al. (2015).

Green Walls and Roofs

Green walls and roofs are another type of vegetated buffer that can effectively reduce air pollution (Tomson et al., 2021). For semiarid climates, like those found in California, USA or Chile in Latin America, Viecco et al. (2018) quantified how much PM10 and PM2.5 was deposited on the leaves of plants on green walls and roofs using an experimental study. Nine species were compared. Comparisons were made by looking at how much particulate matter was found on the wax of leaves since about half of it was deposited in the wax itself as well as how much was found on the outer parts of the leaves. In line with other findings, Viecco et al. (2018) also found that smaller leaves were more efficient in capturing particulate matter. Overall, the plant species found on green roofs and walls were significant in reducing air pollution.

Green walls that have plants with small leaves can reduce particulate matter by absorbing these pollutants (Hozhabralsadat et al., 2022). Plants that have a high water content and ascorbic acid in their leaves were found to be best for green walls which are meant to be in direct contact with pollutants. These two features can increase the air pollution tolerance index (APTI) of plants which is an important feature to improve green wall efficiency. Drought-tolerant plants, plants that do not absorb as much light, and that have lower airflows between its leaves were characteristics and plant types that were found to be effective for improving the APTI of green walls. Carbon and oxygen chemicals were absorbed on the majority of green walls that this study looked at.

Green roofs are similar to green walls and vegetated buffers but are placed on top of roofs. In another experimental study, Arbid et al. (2021) quantified how much NO2 and O3 was removed by plant species commonly used on green roofs. This study looked at both leaves and plants as a whole to calculate pollution reductions. Of the three most effective plant species studied, thyme was the best at removing both air pollutants. The pores of leaves was noted as being important for how the amount of pollutants that are absorbed with thyme having the biggest pores. The next best plant species that removed these pollutants effectively was “Sedum Sexangulare” followed by “Heuchera Americana L” (Arbid et al., 2021). Soil was also beneficial for removing some O3. The results of this study could be used to select plant species.

Parks and Forests

Park features like the amount of trees and vegetation could also play a role in how much air pollution is reduced. Jiang et al. (2022) looked at open versus closed green spaces in parks and the impact of vegetation heights and species types in air pollution reductions for particulate matter. They looked at PM10, PM2.5, and PM1. PM2.5 and PM1 are smaller particle sizes compared to PM10. The different vegetation structures were grouped by the authors based on the percentage of tree canopy and are shown in Figure 2 in their study. Height changed the amount and types of particulate matter that were affected by vegetation. Particulate matter below 1.5 meters was higher than when measured at 5 meters. PM10 was lowest in what was characterized as “partially closed broad-leaved multi-layered forest (PBM)” green spaces in the park whereas PM1 and PM2.5 were lowest in “partially closed broad-leaved one-layered forest (PBO) and then partially open green spaces (PO)” (Jiang et al., 2022). The PBM and PBO structure of parks consisted of 40-70% tree and shrub coverage with the main difference being in layers of forest. The PO structure was partially open with 10-40% canopy. The PBO vegetation structure had the best performance overall for PM1 and PM2.5, though larger particles were more easily captured by green spaces explored.

Another study explored the effects of vegetation in a forest and openness of spaces for air pollution reduction. Gao et al. (2020) looked at particulate matter including PM10, PM2.5, and PM1 as a measure of air pollution similar to Jiang et al. (2022). They found that weather conditions were important in how much particulate matter was reduced. The lowest amounts of particulate matter were found in the “closed single-layered mixed forest” type whereas open green space had the highest concentrations of particulate matter. Open green space that consisted of lawn grass faired similarly to cement surfaces when it came to reductions of air pollutants. Small particles were better absorbed by diverse features from the leaves of plants whereas larger particles like PM10 were reduced more by “closed single-layered mixed forest” than other types of forests. This finding is different from Jiang et al.’s (2022) which found that being partially closed and having mixed layers reduced the larger particulate matter. Having lots of vegetation and biodiversity proved to be beneficial for reducing air pollution.

Having too much or too little green space can change which and how much air pollutants are reduced. Three measures of green space were used to determine the threshold amount to reduce different pollutants by Wang et al. (2022); These include the patch shape index (LSI), patch density (PD) and patch proportion in landscape area (PLAND). Using these measures, they determined that as forest lands increase, PM2.5 decreases with a threshold of up to 18.02 in patch shape index. Increasing patch densities of forest lands, decreased NO2 with the threshold of these effects being up to 0.072. PM10 was not affected by vegetation structures in terms of how much pollution it could reduce and open green spaces did not see any significant reductions in general.

Discussion

Many types of green spaces are available for implementation yet research is lacking for all the different types and best practices for implementing them as a solution to different air pollutants (Kumar et al., 2019). Typically, areas interested in implementing this solution must do their own research into species types and structures that are most effective. One review that helps close this gap looked at the ways that plants and green spaces deposit, disperse, and modify particulate matter (Diener et al., 2021). Another review by Abhijith, K. et al. (2017) looked at specific green space neighborhood interventions and their relationship to air pollution reductions.

As mentioned by Kondo et al.’s (2018) review, many studies around green space, air pollution, and health are cross-sectional and look at these factors at a specific point in time. Many of the articles that were reviewed were indeed cross-sectional. These cross-sectional studies can leave additional questions for those interested in these topics and a need for establishing causality. This finding points to the need for studies that can establish strong associations. One example is having continuous monitoring of air pollutant concentrations before and after green spaces are implemented to evaluate their effectiveness in real world settings. Modeling conditions in a laboratory may not be sufficient to determine the effects of green spaces in urban settings.

Since many studies do not define what they mean by green spaces (Taylor and Hochuli, 2017), comparing green space types has challenges and is the biggest limitation thus far. Many studies mentioned green space but did not define what the term meant for their study nor how the green space had been implemented. Many of the studies that were reviewed did not discuss the environmental conditions present nearby and possible pollutant sources. Weather and street layouts were two factors that were mentioned by multiple studies as being important to how air pollutants are disbursed in green spaces, yet these were not always explored. In studies near road ways for example, it's possible that lower air pollutant concentrations could be due to being farther from vehicle traffic which is often the source of air pollution near roads. Air pollutants can move far and wide to other areas once they are expelled from their source (European Environment Agency, 2016).

Another example is that when Fuller et al. (2017) accounted for additional factors that affect air pollution, they did not find anything significant in changes in air pollutants with green space. Hence, it is important to consider how factors that affect air pollution are also affected by green spaces. Key factors that may also contribute to lower amounts of air pollutants in different countries but were not explored by Meo et al. (2021) include polluting industries and income of the population. Lower-income populations can sometimes be left bearing the burden of pollution of their higher-income counterparts (Tessum et al., 2021). This could also result in weak associations between findings if green space is inherently tied to having higher incomes and less pollution.

Low-income communities in the US may have less green space in general due to historical racism, classism, and lack of investment into these areas. Wolch et al. (2005) found that in Los Angeles, low-income and communities of color have less access to park resources and that park funding is often not allocated to these communities. Park resources could include access and quality of parks. As was discussed, the quality and quantity of green spaces could affect the effects that green spaces have in combating poor air quality. In some cases, vegetated buffers and green spaces can actually increase air pollution if not implemented well. The involvement of experts from different fields can help maximize the benefits of green spaces by ensuring that species types, layouts, weather, and human activities are accounted for.

Conclusion

Although green spaces are a step in the right direction for reducing air pollution and urban built environments, equity considerations are important to achieve maximal benefits for communities. Given that communities of color are disproportionately affected by environmental injustices, care should be taken to weigh risks and benefits of interventions. Potential risks that were not discussed include green gentrification or pollen increases that may come with the implementation of green spaces. Jennings et al. (2021) recommend involving communities into the process of adding green spaces to avoid green gentrification and creating ethics laws for those involved in decision-making such as planners.

At a local level in Los Angeles, CA, green spaces continue to be advocated for by environmental groups and environmental justice organizations. Programs such as TreePeople work on creating more green space in urban environments through tree planting (TreePeople, 2023). Tree planting takes place near homes and pollution sources like industries. Including biodiversity into these efforts will help improve air pollution reductions. Climate Resolve, a climate change driven organization, has also advocated for the implementation of green spaces such as vegetated buffers next to freeways in environmental justice communities like Boyle Heights. As more places work toward implementing green spaces as a solution to air pollution in urban areas, communities will need to decide what features maximize the benefits of this intervention for them.

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