Review

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Green space in health research: an overview of common indicators of greenness

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Abstract: Human environments influence human health in both positive and negative ways. Green space is considered an environmental exposure that confers benefits to human health and has attracted a high level of interest from researchers, policy makers, and increasingly clinicians. Green space has been associated with a range of health benefits, such as improvements in physical, mental, and social wellbeing. There are different sources, metrics and indicators of green space used in research, all of which measure different aspects of the environment. It is important that readers of green space research understand the terminology used in this field, and what the green space indicators used in the studies represent in the real world. This paper provides an overview of the major definitions of green space and the indicators used to assess exposure for health practitioners, public health researchers, and health policy experts who may be interested in understanding this field more clearly, either in the provision of public health-promoting services or to undertake research.

Keywords: environmental health; fractional cover; green space; greenness; NDVI; open space; parklands; urban space.

Introduction

Traditionally, the practice of environmental health was focused on managing adverse environmental exposures, such as unclean water and environmentally transmitted infections [1]. As these traditional risks have declined, at least in developed nations, there is increasing interest in the role the environment plays in protecting health, especially within the context of the built environment [1]. There has been a shift in focus within environmental epidemiology from those environmental agents that cause disease to a focus on the health promoting aspects of the environments in which people live [1]. The rise of planetary health as a research field has given a new focus to ecosystem services; those provisions that arise from the natural world such as clean water, air, healthy food, nutrient cycling, and production of goods [2]. Green space is at the forefront of health promoting environmental research, and exposure to green space has been shown to improve mental wellbeing [3–7], increase physical activity [8–13], and promote social connections [9, 14–19]. Markevych et al. have posited that the pathways through which green space exerts a beneficial effect on health, can be reduced down to three main domains: reducing harm (e.g. from heat), restoring capacities (e.g. improving recovery from stress) or building capacity (e.g. physical activity) [20]. Two recent reviews have highlighted the number of studies finding a positive benefit to health from green space exposure. A series of meta-analyses found green spaces were associated with significant benefits to cardiovascular health markers, a reduced incidence of diabetes and reductions in mortality [21]. There are also benefits to children's health from green space exposure, such as reduction in the number of low birth weight babies, an increase in childhood physical activity, lower risk of obesity and better neurodevelopmental outcomes [22]. The increase in studies showing a positive association between green space and health provides useful information, however the terminology and what the green space indicators represent in the real world is not always clear to the public health workers and health practitioners who may read, interpret, or use the evidence. This paper aims to provide an overview of the major definitions of green space and the indicators used to assess green space exposure. This overview targets health practitioners, public health researchers, and health policy experts who may be

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interested in understanding this field more clearly, either in the provision of public health-promoting services or to undertake health research in this field.

Defining what is meant by the term green space is not straight forward. Different authors posit differing definitions, which may include: public parks; the presence of vegetation, including grasses; undeveloped and/or open land; and forests and nature reserves. There is a distinction between greenness, defined as the presence of any green vegetation, and green space, typically open spaces for recreation or remnant forest. However, published health research does not always make these distinctions clear. This issue was highlighted in a review of public open space papers by Lamb et al. [23], which found that the identified studies defined open space differently, used different sub-types of green spaces, and often did not clearly report what sub-types were included, making comparison across papers difficult. A review by Taylor [24] found that ambiguity in terminology occurs within disciplines as well as across disciplines, and this ambiguity makes it hard to find meaningful understanding across the published literature. The way that green space is defined, and the choice of green space indicators included in research can influence a study's overall findings. A study exploring the association of multiple green space indicators (distance to park, greenness measured by normalised difference vegetation index, and greenness measured by land designated as green space) found that the different indicators were associated with different relationships with overweight subjects [25]. These findings suggest that the green space indicators chosen can directly influence the findings of the research study. In the current paper, the term green space is used as a catch-all term for any measure of greenness, green space, public open space, parklands or tree and canopy cover.

The choice and utilisation of green space measures in health research is influenced by several factors. Researchers may be interested in the purpose of the green space. For example, in studies considering physical activity, the green space measure may be the presence of park lands near the residential home that provide a place to be physically active [26], whereas researchers interested in mental health may consider any greenness, regardless of whether it is located in a park, as equally as important. The availability of data may also influence the way green space is considered in health research. For example, while access to data on park boundaries can be challenging in some contexts, satellite data allows researchers to access data on the quantity of greenness (i.e., vegetation) over large spatial areas. Similarly, while measures of green space quality have previously relied on researcher or participant observations limiting their use to small areas [10], newer methods of remote-assessment of green space quality are emerging [27].

Several measures of green space exist, many of which were developed for purposes outside health research. Two popular metrics are land use (specifically quantifying the area representing green land use) and the normalised difference vegetation index (NDVI), a measure of vegetation greenness. The present assessment will outline common metrics and indicators to enhance understanding of the various terminologies used to describe green space. While the types of indicators chosen by researchers are informed by study objective, design, and practicality, it is important to understand the key differences between widely available indicators. It is also important to note there is a tension between data availability and ideal study design, where data availability plays a role in informing the study design. Additionally, we aim to help readers of green space research to better understand the indicators and what they represent.

Green space indicators

There are multiple ways in which green space indicators can be categorised. For example, green space indicators could be grouped by the domain of public accessibility or quality. Green space can be experienced indirectly, such as viewing trees through a window, or directly, such as visiting a nature reserve, and exposure type also presents an alternative way to classify the indicators. To assist readers, we have mapped our chosen classification system (described below) against the type of exposure they represent (Figure 1). We made the decision to group the different indictors by the type of green space they are measuring, for example general greenness or open spaces, which allows the reader to compare indicators more easily for each category of green space. Therefore, in this section, we will group specific indicators or datasets under broad categories of green space exposure measures. It is useful at this point to define some key terms. There is not a clear consensus on how terminology such as indicator or measure can be defined. In fact, these terms tend to be defined differently depending on the discipline involved. Here we use the terms indicator, metric, and source (Figure 2).

The following section lays out the broad categories of green space sources, metrics and indicators. These are summarised in Table 1, while the following text provides an overview of each indicator/data set and examples of their use in health research.

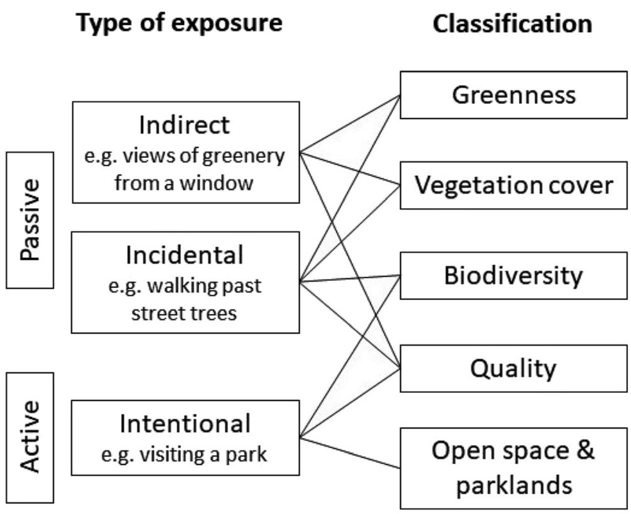

Figure 1: The relationship between green space indictor categories and the type of exposure most commonly occurring to that category.

Measures of greenness

Measures of greenness aim to quantify the amount of green vegetation in an area. They are commonly remote-sensing products that rely on satellite measures of green reflectance. Greenness is a catch-all term for any photosynthetically active vegetation, and includes grass, shrubs, trees and other vegetation types within the image pixel. Greenness can inform researchers on how much green vegetation is present in an area, but not the quality, accessibility or type of vegetation that is present. The following are common metrics of greenness.

Normalised difference vegetation index (NDVI)

The NDVI is a practical and common indicator of green vegetation, used extensively in ecological research [28]. NDVI takes advantage of green vegetation's ability to absorb one form of solar radiation (photosynthetically active radiation spectral region) and reflect radiation from the near-infrared spectral region, which is measured by satellites carrying specialised remote sensing technology [28]. NDVI is calculated as:

$$\text{NDVI} = \frac{\text{Near infrared} - \text{red}}{\text{Near infrared} + \text{red}}$$

The resulting value falls between −1.0 and 1.0 [28]. Values closest to −1 indicate water sources, values close to 0 indicate bare ground or snow. As values increase from around 0.2 they indicate the density of green vegetation, ranging from shrubs and grasslands (0.2–0.4) up to rainforests at near 1 values [29]. Thus, NDVI provides a proxy measure of all greenness in an area. It has been shown to be highly correlated with green vegetation cover compared with on the ground measurements, and can therefore be of value in epidemiological studies [30]. There are limitations to NDVI. Firstly, it cannot differentiate between different types of vegetation or measure the biodiversity of a given area [30, 31]. There can also be differences in spatial scales of NDVI that is available compared with the study areas, and by itself it does not distinguish between public or private spaces [32]. Lastly, it only provides information on green vegetation and lacks information about dry or dead vegetation or a clear indication of the amount of bare earth in a given area. An example of NDVI is shown in Figure 3.

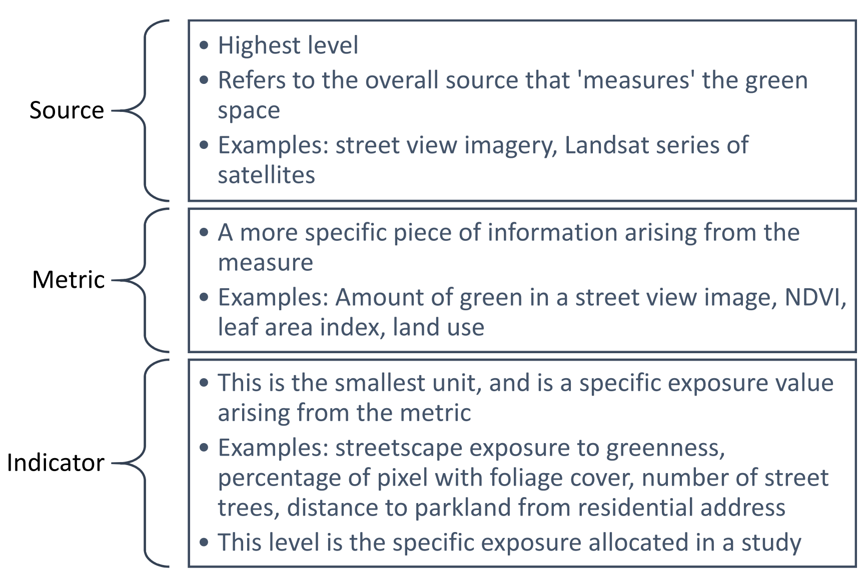

Figure 2: Hierarchy of terminology used to define green space.

Table 1: Summary of green space indicators.

Exposure classification	Brief definition	Sources from which indicators can be derived[a]	Example metrics and indicators[a]	Example/s of use in health research[b]
Greenness	Measures all greenness in the environment, such as grass, shrubs, trees	Satellite imagery Aerial imagery	Vegetation indices such as normalised difference vegetation index (NDVI) or enhanced vegetation index (EVI)	Asthma [65, 66, 75]; wellbeing [63]; mental health, mortality (heat, CVD, stroke, lung cancer, self-harm, respiratory disease, diabetes, traffic accidents), physical activity, perceived health and wellbeing, birthweight, BMI, neonatal outcomes, obesity, ADHD, hormone concentrations, immune function [84]
		Google street view imagery	% Green pixels	Physical activity [85]
		Satellite imagery	Fractional cover	Birthweight [86]
Open space and parklands	Measures of open green spaces, such as parks or undeveloped land. Not all sub-types will represent publicly available land	Land cover from satellite imagery	Distance from home to nearest park along the road network	Physical activity [81, 87]
		Land use data	% Area in open space within 400 m straight line distance around residential address Percentage of green space in spatial unit	
		Researcher observation	Presence of a park within 15-min walk from home Researcher rating of high level of green space in given area	Self-reported general health, perceived stress scale, physical activity and active transport [17]; improved emotional experiences [7]; stress reduction [42, 44]; reduced rumination [43]
		Participant survey	Perceived vs actual distance to nearest park	Physical activity [45]
Quality of park-land or open space		Researcher observation Participant survey Remote assessment using satellite info and/or publicly available information	Attractiveness Activities Environmental quality Amenities (e.g., paths, lighting, seats) Safety	Self-reported general health [17, 48], perceived stress scale, physical activity and active transport [17]; physical activity [41, 46]; body weight [47]; mental health [48]
Vegetation cover		Satellite imagery LIDAR	Foliage projective cover Tree counts	Birthweight [86] Asthma [88]
Biodiversity		Taxa surveys Citizen science (e.g., eBird)	Shannon's index	Respiratory health [60]
			Species richness	Wellbeing and perceived stress [61–63, 67]; perceived health benefits [64]; asthma [65, 66]
			Remnant forest	

[a]In this paper, indicator refer to the lowest level of the green space information hierarchy and represents the specific exposure, a metric is a larger piece of information, while the source is the highest level which refers to the overall source of the metrics and indicators.
[b]These are examples of each indicator's use in health research and is not exhaustive.

Figure 3: This panel shows (clockwise from top left). Queensland globe aerial image of Jandowae, Queensland with mapped nature conservation and recreation land uses in green, NDVI image from Sentinel 2 with index values shown as shades of green, fractional cover image from Sentinel 2, with vegetation cover shown as shades of brown and Mapillary streetview image taken at the location of the red point.

Fractional cover

Fractional cover is a measure of ground cover that gives values for the amount of green cover, dry cover, and bare earth in a given area [33]. Dry cover is comprised of dead vegetation, branches and leaf litter, while bare ground is soil and rock [34]. Fractional cover is produced from remote sensing products using algorithms to predict the proportion of each component of the fractional cover [33]. While the green fraction is highly correlated with NDVI, fractional cover attempts to give more meaningful understanding of the ground cover beyond greenness, and is particularly relevant in areas prone to long periods with low rainfall [35]. Extensive fieldwork sampling has been performed to validate the reliability of fractional cover data [33, 35, 36] to produce a globally consistent product [37]. An example of fractional cover is shown in Figure 3.

Measures of open green space and parklands

This category of green space includes private and public open green spaces such as forested land, golf courses, public parks, undeveloped land, land within private institutions, or natural land around waterways [23]. The level of public access depends on the ownership of the land parcel, restrictions on entry or use of the space, and safety issues such as maintenance of pathways or overgrown vegetation. Researchers may be interested in the presence of the green space, the quantity of green space or some element of the accessibility of the green space. The green space in this category is typically used to indicate land available for recreational purposes, both formally (e.g. dedicated parklands) and informally (e.g. undeveloped land used by local residents for walking or games), but it is important to note that not all measures of open space differentiate between land that is publicly available vs. private or pay-for-use facilities. An example image can be found in Figure 3. The following are common measures of open green space.

Land use, parks or public open space data

Presence and accessibility measures of green space in health research are usually created using land use data. Land use data are typically government data prepared for administrative purposes, such as planning or land taxes [23]. Categories related to recreational uses (such as parks or sports fields), undeveloped land or forests are typically classed as green [24]. Depending on the categories available, land use data can allow the mapping of open spaces near the residential home, or within the boundaries of an administration unit, and can allow researchers to target specific types of land that align with their research aims. However, there are issues related to the reliability of these data. Land use data indicates the intended purpose at the time of planning. The actual use of the land, resident access to the land, or the amenities present may differ from that presented in the data [23]. A handful of studies quantifying differences arising from use of different sources of land use data to calculate measures of green space vary in their results, with some showing a reasonable correlation across data sources [38], and others showing poor correlation [39]. This is likely due to the different datasets being compared. For researchers aiming to measure green space, it is important to be aware that there are different sources of land use data, and the choice can potentially change the exposure measures and therefore research results. For a recent comparison of regional and global open access datasets for greenspace mapping see Liao et al. [40].

Researcher or participant observation of green space

Another method of assessing the presence of green space is visual inspection by researchers. This has been used in several studies, and involves either the research team assessing the quantity of green space available [17, 41], or having the research team choose sites that represent high and low green space [7, 42–44]. Participant observation of their access to green space is another method, however it tends to have poor correlation with objective measures [45].

Quality of green space

Quality is an important aspect of open green spaces that may refer to the presence of suitable facilities, the attractiveness of the green space and aspects of safety, among others. Higher green space quality has been linked to improvements in a range of health outcomes including physical activity [46], overweight/obesity [47], mental health [48] and self-rated health [48]. Green space quality can be measured quantitatively (e.g., a count of park facilities) and qualitatively (e.g., subjective assessment of quality of facilities), and is frequently a composite measure that combines these domains to give an overall score. For example, a study in the Netherlands used a six-item scale to give an overall quality score based on facilities and amenities within parks, natural features, maintenance, accessibility, and lack of public mess such as graffiti and animal droppings [46].

Researcher or participant rating of quality green space – direct observation

Direct assessment by either researchers or participants is a common method used to assess quality. Previous studies have surveyed park users on their perceptions of the quality of the green space near their homes [10, 49, 50] or had the research team assess the quality or attractiveness of green space available [17, 41]. Several validated questionnaires exist for the purpose of assessing parklands and open space, such as the Environmental Assessment of Public Recreation Spaces (EAPRS) [51], the Public Open Space Tool (POST) [10] and the Children's Open Space Tool (C-POST) [52]. The quality of a green space can influence physical activity. The POST tool was used by trainer assessors to rate the attractiveness of open spaces in the study area. The study found that participants were more likely to engage in walking for recreation and fitness in their neighbourhoods when they lived near an open space rated as attractive in the quality scale [26].

Assessment of quality by remote techniques

Newer methods that leverage the availability of satellite images allows for remote assessment of park quality. One resource is the Public Open Space Desktop Auditing Tool (POSDAT) which draws on numerous public, government and private information sources (publicly available park information, high resolution orthoimages, Google Earth and Street View products, among others) to create a tool which allows researchers to remotely assess the attractiveness and amenity of public parks [27]. Validation of the POSDAT has shown good reliability with direct observation [27].

Trees and canopy

The presence of trees in an area is a common green space measure, and captures different information compared to the previous measures. Often trees and canopy cover are not intended to show presence or access to green spaces, but aim to capture different amenities specifically related to trees such as cooling [53, 54], reduction of air pollutants [55] and pleasant visual aspects [6]. There are multiple tree related measures from two broad categories: the number of trees present or the quantity of the canopy cover of trees in a given region. Canopy cover can be further broken down into the overall size of the tree canopy or the area of the canopy which provides leaf coverage.

Tree counts

Tree count measures include a count of the raw number of trees, or the percentage of trees in the research area. Tree locations can be identified via a number of data sources including satellite maps, street view data, or local government data. Efforts have been made to validate the use of street-view data to create an index of urban greenery specific to trees [56].

Tree cover

Tree cover is a broad term that refers to the layer that is formed by the crowns of trees projecting upwards [57]. Tree cover can provide significant shading opportunities, especially when densely placed, which contributes to local ground cooling. There are four major indices to define the tree cover in an area: canopy cover, foliage cover, foliage projective cover (FPC) and leaf area index [58]. Canopy cover gives a value for the proportion of the ground covered by the vertical projection of the tree crowns [59]. At its most basic, canopy cover measures the two-dimensional size of the crown when looking at images, commonly from remote sensing products, taken directly above the tree (looking downwards), [59]. The leaf area index is the one-sided green leaf area per unit ground surface area [57]. Foliage cover is the proportion of the ground covered by all canopy material, such as sticks, trunk and leaves, while FPC is the proportion of ground covered by foliage (leaves) only [58]. FPC gives a more accurate measure of the amount of shade, as different trees have different leaf size, orientation and density [58].

Biodiversity and vegetation types

Biodiversity relates to the variety and variability of species present in a given area. Typically, this would relate to all living organisms, including plants, insects and animals. Within green space research, there is increasing focus on biodiversity and health. Preliminary evidence suggests that biodiversity could relate to improved respiratory health [60], higher levels of wellbeing [61–64], and reduced odds of asthma [65, 66]. While mechanisms linking biodiversity and health are still unclear [67], these may include the immune system development and regulation [68], restoration and stress recovery [69].

Biodiversity indices

Biodiversity indices are largely created to monitor the health of environmental ecosystems and assess the effects of human activity [70], yet are increasingly used in health research. Biodiversity indices assign a number to an aspect of biological diversity [71] and can incorporate variety and/or abundance [72]. In green space and health research, measures of biodiversity have included plant species richness (e.g., [65, 66]), bird species richness [73], and fauna species richness [63]. The data used to calculate measures of species richness can either be based on objective data (e.g., counts of taxa in an area), or participant reported perceived species richness. For example, a well-known measure of diversity in this context is Shannon's Index, which measures the species richness and species variation within a given area and gives a composite value [72, 74].

Discussion

We introduced a range of green space measures that can be leveraged in health research, and explained what they measure, and highlighted examples in the literature. We have discussed how the common green space indicators can be categorised into five main types: measures of greenness, measures of open space and parklands, quality of green spaces, trees and canopy, and biodiversity and vegetation types. These five categories include several different indictors, but at their heart they represent different elements of green space that confer different types of benefits. Understanding these categories, what they represent and the advantages/disadvantages of their use in health research, will improve our understanding of their role in human health research.

This paper covers some of the most common measures used in health research, however there are other measures of green space in different fields that may also provide useful information when applied to health outcomes. For example, remnant ecosystem measures quantify the predominate vegetation types that naturally occur in a regional ecosystem, and how much remains. A measure such as this could provide useful information in understanding any association between green spaces and allergic asthma, especially since previous studies have found contradictory findings [75–77] that may be partially explained by vegetation species. Newer methods have been developed to assess the amount of greenness at eye-level for persons on the ground, improving upon measures such as NDVI by more accurately measuring the visibility of green spaces [78].

When selecting the green space measures to use in studies, the research goals and health outcomes of interest should act as a guide. As stated in Lamb's review, health researchers tend to place emphasis on the outcomes and may choose green space measures out of convenience [23]. In this case researchers must be aware of what each green space measure represents to ensure it is appropriate for the outcome of interest. Ekkel [79] advises using multiple measures in future research, which is supported by the study by Klompmaker et al. [25] which found different indicators had a different relationship with body weight outcomes. Importantly, Taylor and Hochuli call for researchers to give clear definitions of green space in their study; calling specifically for definitions to include a qualitative description of the greenness measure used (e.g. all greenness in the study area such as grasses, shrubs and trees) and a qualitative indictor (e.g. measured by NDVI) [24].

Researchers and policy makers should also be aware of the limitations of the data used to measure green space, much of which is collected for purposes outside of health. Mavoa et al. have shown that the same metric, when calculated using different land use data sources, do not always correlate with each other [80]. The authors took three sources of land use data, including the commonly used MeshBlock data, and compared the geographic patterns in the same area [80]. Slight differences were found across all three sources [80]. This discrepancy across datasets has been found by other researchers, as well as the importance of the spatial unit chosen. Daker et al. found that larger spatial units showed better agreeance between datasets, but this was largely because the larger unit masked a lot of the internal variation within the unit [39]. This is important as data custodians of large routine health records tend to favour larger spatial scales when assessing data access requests, however the larger units may not best answer the research question.

While this paper focused only on green space specific metrics it is worth noting that other attributes of the surrounding environment may determine use of and exposure to green spaces. For instance, studies have shown that features of the surrounding neighbourhood (e.g., walkability, safety) can be associated with park use and activity [81, 82].

Conclusions

The value of green spaces to health is recognised by clinicians, policy makers and researchers. The value of "time in nature" as a therapeutic strategy for improving mental health outcomes is now recognised as a legitimate intervention [83]. When drawing on published studies, it is important to understand what aspect of green space the study was measuring. Similarly, researchers should carefully consider their choice of green space indicator to achieve their study goal. Green space indicators can be categorised into five groups, with each conferring different benefits. Understanding these five categories will assist all stakeholders to obtain the most benefit from the findings of green space research.

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