**Target Journal: Environmental Research Letters (Health)**

**Single or double anonymous (author choice)**

**Title**

Health impacts of changes in urban greenspace across 1,042 global cities

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**Keywords**

Health impact assessment, greenspace, blue space, Normalized Difference Vegetation Index, NDVI, urban nature

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**Abstract**

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**Introduction**

*This should be concise and describe the nature of the problem under investigation and its background. It should also set your work in the context of previous research, citing relevant references. Introductions should expand on highly specialised terms and abbreviations used in the article to make it accessible for readers.*

Importance of greenspace as climate resilience and population health intervention

Importance of cities as a focus

Context of LCD

Over half of the world’s population lives in cities and this share is predicted to grow to two-thirds by 2050 (Alex Baeumler et al. 2021).Urbanization has been accompanied by the pollution of natural resources and destruction of natural environments. It is estimated that cities are responsible for over 80% of global greenhouse gas emissions (Hoornweg, Sugar, and Gomez 2020). Although cities are the biggest contributors to climate change, they can also be effective entities of change. Cities can provide a large enough scale to create meaningful change while remaining small enough to test policies that might not be feasible at a national scale. Increasing urban nature is an intervention at the city-level that is linked to health benefits as well as climate resilience.

The Lancet Countdown is an annual publication dedicated to tracking progress towards the goals of the Paris Agreement and documenting the health implications of climate change. Urban greenspace has been included as a metric in the Lancet Countdown since 2020.

While the climate benefits of policies aimed at climate change mitigation are geographically dispersed, the health benefits of such policies are often concentrated locally. Because of this, climate mitigation and adaptation policies with health co-benefits tend to be an easier sell. Quantifying these co-benefits can therefore serve as an impetus to climate action, as they provide a more immediate pay-off in terms of health gains and healthcare dollars saved. While the health co-benefits of reducing air pollution have been widely recognized and studied (Thompson et al. 2014; Thurston 2013; West et al. 2013), there is less information on co-benefits from policies that increase urban green and blue spaces, or natural space.

The most common metrics used to quantify greenspace in the epidemiologic literature are the normalized difference vegetation index (NDVI) and land cover data sets. NDVI is a satellite-derived measure that uses visible and near infrared light to quantify the density of vegetation. Because chlorophyl, a green pigment found in plant leaves, absorbs visible light (VIS) for photosynthesis and plant cell structures reflect near-infrared (NIR) light, the combination of these wave lengths can be used to differentiate not only vegetation from other surfaces but also the health and density of vegetation (NASA Earth Observatory 2000). NDVI is calculated as (NIR-VIS)/(NIR +VIS) and ranges from -1 to 1. Values near zero represent no vegetation (e.g. urban areas, dirt), while negative values are usually clouds, water, snow, or ice. Broadly, values between 0.6-1.0 can be thought of very healthy plants. Studies using NDVI generally define greenspace as the average NDVI of the greenest season in a certain geographical or administrative boundary or within a certain buffer of the target population. The advantage of NDVI as a measure of greenspace is that there is global coverage on a fine spatial and temporal scale. NASA’s Landsat 8 satellite produces imagery suitable for calculating NDVI every seven days at a 30m-by-30m resolution. The main limitation of NDVI is that it does not provide information on the type of greenspace, nor its accessibility or quality. Land cover data sets, on the other hand, do contain insight into the type, and perhaps functionality, of greenspace. However, because they classify each pixel by its primary type, they can miss smaller scale urban greenspaces such as tree-lined streets or small parks. Additionally, they are updated less frequently. Studies using land cover maps to define greenspace generally calculate the percentage of green area within a geographic or administrative area.

The literature on blue space is less established, and epidemiologic studies of blue space exposure have employed a wide range of metrics. In a systematic review of 50 studies on the relationship between blue space and health, 17 different measures of blue space were used (Georgiou et al. 2021). Some of these exposure metrics included the presence of blue space within in various buffers of a person’s home, residential proximity to a coastline, the percentage of blue space in a certain geographic or administrative area, measures of activity near water from personal monitors or self-report, self-reported accessibility, frequency of visitation, or proximity to water, and satellite-derived measures such as the normalized difference water index (NDWI). Despite NDVI being the most popular measure to define greenspace, studies where green and blue spaces have been combined tend to use land cover datasets to define their exposure (Gascon et al. 2018; Kabisch et al. 2019; de Keijzer et al. 2019; Nieuwenhuijsen et al. 2018). This approach loses information on finer scale green and blue spaces in urban areas.

Observational studies have found that exposure to greenspace is associated with a range of health benefits. A 2018 systematic review and meta-analysis of exposure to greenspace and health outlined the four main pathways that are hypothesized to link greenspace with health: increased physical activity, increased social interaction, exposure to sunlight, and exposure to microorganisms (Twohig-Bennett and Jones 2018). The authors also note mitigation of harmful environmental effects, such as the urban heat island effect as well as air and noise pollution. The authors found that increased greenspace was associated with decreased salivary cortisol, heart rate, diastolic blood pressure, and HDL cholesterol, decreased risk of preterm birth, type II diabetes, and cardiovascular mortality, as well as increased incidence of good self-reported health (Twohig-Bennett and Jones 2018). Furthermore, greenspace was protective against all-cause mortality, with a risk ratio of 0.69 (95% CI: 0.55, 0.87) (Twohig-Bennett and Jones 2018). A 2019 meta-analysis using longitudinal studies of the association between NDVI and all-cause mortality, reported a pooled hazard ratio of 0.96 (95% CI: 0.94-0.97) per 0.1 increase in NDVI within a 500m buffer of a person’s residence (Rojas-Rueda et al. 2019). This study had the benefit of using solely longitudinal cohort studies with a common exposure definition. One additional meta-analysis of greenspace and all-cause mortality has been published since the Rojas-Rueda et. al study, however it looked specifically at elderly individuals (Yuan et al. 2021).

Exposure to urban blue space parallels greenspace in its hypothesized health benefits and mechanisms of action. While urban blue space has been less studied, a few recent systematic reviews highlight the health benefits of blue space. A 2021 review and meta-analysis delineates four casual pathways: social interaction, restoration (e.g. a reduction in stress, anxiety, depression, etc.), environmental factors, and physical activity (Georgiou et al. 2021). This meta-analysis found that living closer to blue space was associated with increased physical activity, living near large bodies of water was associated with higher levels of physical activity and restoration, visiting blue space more often was associated with increased restoration, and the presence of blue space was associated with beneficial environmental factors (Georgiou et al. 2021). Because they tested each exposure metric (e.g. distance to blue space, quantity of blue space) and hypothesized causal pathway (e.g. physical activity, social interaction) combination separately, they were limited in their statistical power. This reflects the fact that there is still no clear consensus in how blue space should be measured. Seventeen different exposure metrics were used in the 50 included studies of this meta-analysis (Georgiou et al. 2021). Another 2021 systematic review and meta-analysis focused specifically on urban blue spaces and human health. It found a protective effect of blue space within 500m of a person’s residence on all-cause mortality, with a pooled hazard ratio of 0.99 [95% CI: 0.97, 1.00] (Smith et al. 2021). This estimate was based on three studies, all of which defined blue space with different metrics.

The epidemiologic literature describing the effect of exposure to blue space, and to a lesser extent greenspace, on all-cause mortality suffers from a lack of comparability in exposure definitions. Still, these studies show a consistent positive association between natural space and health. While evidence for greenspace is more robust than that of blue space, both exposures are hypothesized to benefit health through similar mechanisms. In addition to studies quantifying the exposure-response function between greenspace and health, a few recent studies have applied these findings to conduct health impact assessments. A 2021 health impact assessment estimated the number of deaths associated with insufficient exposure to greenspace across 978 cities in 31 European countries (Barboza et al. 2021). The authors found that if these cities met the World Health Organization’s recommendation of universal access to greenspace, 42,968 natural deaths could be avoided annually (95% CI: 32,296, 64,177) among adults aged 20 and over (Barboza et al. 2021). A similar health impact assessment of greenness in American cities found that 38,000 deaths (95% CI: 28,640-57,281) among those 65 and older could have been avoided in 2019 across the 35 most populous metropolitan areas of the United States if NDVI was increased by 0.1 (Brochu et al. 2022).

**Method**

This section should provide sufficient details of the experiment, simulation, statistical test or analysis carried out to generate the results such that the method can be repeated by another researcher and the results reproduced.

Analysis changes:

* Changed seasonal dates to non-overlapping (i.e. December 1 to Feb 28 instead of Mar 1)
* Changed handling of negative NDVI values
  + JRC global surface water data set to mask water pixels (2015 and 2020)
    - Used just permanent water not seasonal water
  + Left remaining negative pixels (urban areas) as is
* Changed data set for 1km population from GPW population density to GPW population count
* Changed shape file upload. Old file had two cities (Sio TomA and Male actually pointing to Port Moresby, PNG)
* In old version SioTomA not in final results file but included in the shapefile upload
* Landcover- did not mask water in calculation of green area

**Results**

The results section should detail the main findings and outcomes of your study. You should use tables only to improve conciseness or where the information cannot be given satisfactorily in other ways such as histograms or graphs. Colour should not be used in tables, if you need to denote different things in a table then you can use bold or italics etc. providing no coloured text or shading is included. Tables should be numbered serially and referred to in the text by number (table 1, etc.). Each table should have an explanatory caption which should be as concise as possible.

**Discussion**

This should discuss the significance of the results and compare them with previous work using relevant references.

**Conclusion**

This section should be used to highlight the novelty and significance of the work, and any plans for future relevant work.

**Acknowledgements**

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* there is good contrast between adjacent colours;
* colours are distinguishable if the figure is converted to greyscale;
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