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The importance of green spaces to public health: a multi-continental analysis

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Running head: Green spaces and public health

As green spaces are a common feature of liveable cities, a detailed understanding of the benefits provided by these areas is essential. Although green spaces are regarded as a major contribution to the human well-being in urbanised areas, current research has largely focused on the cities in developed countries and their global importance in terms of public health benefits remains unclear. In this study, we performed a multiple linear regression using 34 cities in different regions across the globe to investigate the relationship between green spaces and public health. Our analysis suggested that for richer cities, green spaces were associated with better public health; whereas a greater area of green spaces was associated with reduced public health in the poorest cities. In contrast to previous studies, which typically found positive relationships between green spaces and health benefits, we demonstrate that health benefits of green spaces could be context dependent.

Keywords: cities; ecosystem services; health benefits; human wellbeing; green infrastructure; mental health; wealth.

Introduction

Urbanisation is linked with a shift in the burden of disease from acute childhood infections to chronic, non-communicable diseases of adults (Dye 2008). The incidence rates of psychosis and depression, for example, have been shown to increase drastically with growing urbanisation (Sundquist et al. 2004). However, the urban environment also provides opportunities to address several of some major health issues. Urban green space, in particular, has been linked to reductions in several diseases which are highly prevalent in many cities and often the targets of costly, large-scale prevention programmes (Maas et al. 2009). Therefore, there is much potential to shape cities for better health outcomes. More than half of the world's people now live in urban areas and the proportion will rise to two thirds by 2050; the urban population will reach 6.4 billion people by 2050, driven by high rates of urbanisation and population growth (United Nations 2014). Understanding how health is affected by urban environments is therefore of the upmost importance.

Health can be defined as both the absence of ill health and the presence of mental and physical well-being (Rydin et al. 2012). Urban green spaces are associated with health benefits, particularly of the city dwellers (van den Berg *et al*. 2010), which may be realised directly through enhancing psychological well-being (Irvine et al. 2013), or indirectly via promoting outdoor physical activity (Rydin et al. 2012). These benefits of green spaces are likely to be especially important in this 'urban century' in which our urban lifestyle has increasingly disconnected us from nature (Miller 2005).

Evidence of health benefits of urban green spaces, however, is largely derived from developed countries (Van den Berg et al. 2015). Given that almost 90% of the increases in the urban population will be concentrated in Asia and Africa (United Nations 2014), there is a need to consider the importance of green spaces in cities worldwide. Applicability of current insights, often gleaned from the developed world, to poorer cities remains unknown. This paper investigates the relationship between green spaces and public health in 34 cities across the globe, hypothesising that good public health is generally associated with urban green spaces. In contrast, cities with less green spaces would suffer relatively poorer public health.

Material and methods

Green space and health data

We derived the total area of green spaces per capita (i.e. the sum of all public parks, recreation areas, greenways, waterways, and other protected areas accessible [in close proximity] to the public [Fig. 1]; expressed as m^2 green space per inhabitant) for 34 cities from the Siemens Green City Index (Economist Intelligence Unit 2012a) which provided green space data for cities in Africa, Asia, Latin America and North America (Fig.2a). Although this data source covered more than 120 cities around the world, a majority of the cities – including those from Europe and the Pacific countries – lacked information on the areas of their green spaces. Thus, the inclusion of these 34 cities for this study was solely based on their data availability. To ensure that the data was comparable across the cities, we restricted our study to only one data source for consistency in terms of the demarcation of city area, the quantification of city population size, as well as the definition of green spaces (see Taylor and Hochuli 2017).

We used the LSE Cities Health Index as a proxy for health of city populations (Paccoud 2011, Fig.2b), which was calculated for the ‘extended metropolitan regions’ – a new spatial unit intended to provide a degree of geographical comparability between metropolitan areas across countries (Paccoud 2011). Although this index, based on the United Nations Development

Programme's Human Development Index (hdr.undp.org/en/reports/global/hdr2010**)**, used both life expectancy and infant mortality as the main health indicators, it was positively correlated with the cities' life expectancy figures where they were available (n = 29; correlation coefficient = 0.94). Hence, this health index strongly represents a health dimension – i.e. life expectancy – that would have logical, tangible pathways to outcome from increased levels of green space (see Table 1 for the hypothesised pathways).

Explanatory variables

In addition to green space, eleven other explanatory variables were considered to account for factors known to influence public health: (i) LSE Cities wealth index (compiled from Paccoud 2011); (ii) Population density (people per km^2; Paccoud 2011); (iii) Natural assets index (from 1 [best] to 5 [worst], based on the presence of natural features – such as river, lake and mountain – within 100 km from the city centre, and protected areas in a 75 km radius; Economist Intelligence Unit 2012); (iv) Pollution index (ranged from 1 [best] to 5 [worst] , based on the concentration of particulate matter of >10 micrometres [PM10] in the air; Economist Intelligence Unit 2012); (v) Sunshine (annual mean number of hours; World Meterological Organisation, http://www.wmo.int/pages/index_en.html); (vi) Stability index (ranged from 0 to 100 [ideal], based on the prevalence of petty and violent crime, threat of terror, military conflict and civil unrest; Economist Intelligence Unit 2012); (vii) Healthcare index (ranged from 0 to 100 [ideal], based on the availability and quality of public and private healthcare and medicines; Economist Intelligence Unit 2012); (viii) Culture and environment index (ranged from 0 to 100 [ideal], based on weather condition and quality of living in terms social freedom, censorship, availability of sporting and cultural events, food and drinks and consumer goods and services; Economist

Intelligence Unit 2012); (ix) Education index (Paccoud 2011); (x) Infrastructure index (ranged from 0 to 100 [ideal], based on the quality of road networks, public transport and international links, availability of good housing and quality of energy, water and telecommunication provisions; Economist Intelligence Unit 2012); and (xi) GDP per capita (US$ per city resident in 2012; Istrate and Nadeau 2012). Admittedly, datasets of the same year were not possible to obtain. However, we have integrated the most recent, comparable datasets for our analysis. The variables considered and key hypotheses relating to these variables are summarised in Table 1.

Statistical analysis

We first examined all explanatory variables for collinearity with Pearson's correlation tests (Table S1) and eliminated less-informative parameters of strongly correlated variables ($|r| > 0.65$) for the subsequent multiple linear regressions. Wealth index was strongly correlated with pollution, stability, healthcare, culture and environment, education, infrastructure and GDP per capita; these variables were therefore excluded from the analysis. As a result, the explanatory variables were green space, wealth index, population density, natural assets index and sunshine. We also included in the analysis the interaction between green space and wealth index, as benefits of green space could vary depending on the economic status of cities. All explanatory variables were standardized for their effect sizes to be compared. We used logit-transformed health index as the response variable to achieve normality.

We applied simple linear regression models and used the function 'dredge' within the package MuMIn (Bartoń 2012) in R (R Core Team 2014) to run model selection based on Akaike Information Criterion (AIC; Akaike 1973), comparing models for all possible parameter subsets in terms of parsimony and prediction. We used AICc due to a small sample size (n/K <

40). The difference in the AICc values between the best model (i.e. one with the smallest AICc value) and other models (Δ_i) was calculated. Models were ranked in order of increasing Δ_i. Next, Moran's *I* was calculated for the residuals from the full models, using the package ncf (Bjørnstad 2005) in R, to investigate the effect of spatial autocorrelation. The calculated Moran's *I* was between -0.39 and 0.42 for all distance classes, indicating no more than a weak autocorrelation. Thus, spatial autocorrelation was not considered explicitly in the model for the analysis. Data used in the analysis are provided in Table S2.

Results

Model selection showed that green space, wealth and their interaction appeared in all top five models including two with $\Delta_i < 2$ (Table 2). The estimated coefficient of green space was negative in those models. However, the coefficient of the interaction between green space and wealth was positive and much larger than the absolute value of the coefficient of green space. This suggests that the association between green space and health depends on the level of wealth; the relationship was positive for the wealthiest cities (Fig.3), indicating that increases in green space are associated with better health. Contrastingly, green space was associated with reduced health for poorer cities, especially those in the poorest category (Fig.3). The positive coefficient of wealth indicates that health of city populations is better in wealthier cities (Table 2). The adjusted R-squared value of the best model was 0.766.

Discussion

Our results showed that public health in cities was associated with green space and wealth, as well as the interaction between these variables. Therefore, the relationship between green space and health has to be interpreted for cities with varying wealth levels. For wealthy cities, green space was associated with increased health, in line with a considerable body of literature demonstrating the positive effects of green space on health mediated by direct psychological benefits, greater physical activity and improvement in environment (see Table 1). Although we could not include in our analysis many European cities due to the lack of their coverage in the data source, incorporating those European cities – many of which are wealthier and have relatively more green space as well as better public health compared to other part of the world – would further reinforce the positive relationship between green space and health among wealthy cities. In contrast, increasing green space was associated with decreased health for the poorer cities. We propose three plausible but interlinked interpretations of this trend.

First, lower income cities may have a larger proportion of poor quality green space. Green space could be highly heterogeneous (Su et al. 2011) and may differ in terms of aesthetic appeal, range of facilities, availability of organised recreation, perceptions of safety, upkeep and reputation; which may in turn affect the magnitude of benefits they provide (Wilebore and Wentworth 2013). Poor quality green spaces – characterised by more crime prone (Kimpton et al. 2017) and pronounced concentrations of physical incivilities such as graffiti and the presence of boarded up or vacant buildings, limited provision of facilities for physical exercise and locational drawbacks such as being near to industrial sites and multi-lane roads (Coen and Ross 2006) – may evoke fear and insecurity and inhibit use (Koole and Van den Berg 2014); and be detrimental to health (e.g. higher air pollution in parks near highways in low income neighbourhoods; Su et al. 2011). More green areas in poor cities may imply that their residents could have a greater exposure to the health risk associated with low quality green space. This also means that these green areas – that are of particular importance to certain social groups such as children (Dadvand et al. 2015), women (McEachan et al. 2016; Sang et al. 2016) and older adults (Wolf and Housley 2016) – will not be able to contribute to their well-being (Corburn 2017).

Second, public support and engagement has been linked to well-maintained green space (Wilebore and Wentworth 2013). Those in impoverished cities may have different attitudes towards green space, and community participation is likely to be much lower (Muhumuza and Balkwill 2013). The developed countries' ideal of green space as a place for recuperation, rejuvenation, social interaction and physical activity is not necessarily shared in financially-needy cities in different regions, which may exacerbate differences in quality and benefits derived from green space (Stodolska et al. 2011; Roe et al. 2016; Ives et al. 2017). Furthermore, green spaces may not be used even if they were of high quality due to ethno-cultural values (Li 2014; Ordonez-Barona 2017).

Lastly, unprosperous cities may face greater problems regarding access to green space compared with wealthier cities. The distribution of green space affects the benefits it engenders; the distance to urban green spaces, in particular, has been suggested to be of decisive importance (Grahn and Stigsdotter 2003; Gascon et al. 2015). Access to green space is often highly stratified, based on axes of difference such as income and ethno-racial characteristics (Wolch et al. 2014). It is highly plausible that lower income cities may, therefore, have a larger proportion of green space which is not accessible to the many and so cannot deliver the expected health benefits**.** Moreover, even when accessibility and use may not be an issue, it is possible that the green spaces in these poorer cities may have elements – such as pests (e.g. mosquitoes and rats) and allergens (pollen) – that are potentially harmful to public health (Lohmus and Balbus 2015).

Further, based on our results in Fig.3, we can also hypothesise that an increase of green space for the very affluent cities (e.g., Osaka, Tokyo, Singapore and Hong Kong) may result in only a small improvement on their health status. Nevertheless, considering that the LSE Cities Health Index, used in this study, is a quantitative measure that reflects life expectancy only, this hypothesis as well as the potential negative association between green space and health in poorer cities will need to be tested using other health indicators including those measuring mental health. Despite this study used the most comprehensive global database on city green space, the sample size of the analysis is admittedly not large. Although many variables that could influence the health outcomes from green spaces (see Table 1) were included in the analysis, other potentially relevant variables such as city expenditures on green spaces (Commission for Architecture and the Built Environment 2006), public accessibility (Seeland et al. 2009) or proximity to people (O'Brien and Morris 2013) were not captured due to limited data availability. Further, the database does not include cities in some regions, such as Europe. Thus, it will also be important to expand the analysis to a wider range of cities globally when appropriate data become available, in order to explore the applicability of our findings. Last, cross-city analysis such as this study may not provide the necessary resolution to discover the role of inter-personal differences (e.g., cultural [Rishbeth 2001]; gender [Jorgensen et al. 2002]) that may impact on the way people experience with green spaces.

In conclusion, given its potential contributions to public health, the green space benefits could be actively planned for, promoted and maintained across the globe. Nevertheless, our finding indicates that we need to address specific challenges regarding quality, access, engagement and epidemiology, for green spaces to truly have a positive role in health for urban inhabitants. From a global perspective, the priority is to improve health outcomes for the many city-dwellers at the bottom of the socioeconomic spectrum (Rydin et al. 2012). A redesign of open green spaces in relation to today's urban context and needs, preferences and health problems of modern citizens (Grahn and Stigsdotter 2003) may be required in cities where urban green spaces are present, but are not eliciting the accompanied health benefits (i.e. 'green spaces advantage'). Investment in green space in poor cities, further research into necessary attributes and transferring proven best practice will hopefully allow the 'green space advantage' realised in wealthy cities, to become a reality for impoverished cities. Last, in poorer cities where changing the urban environment or redesigning the urban green spaces is not possible, awareness-enhancement programmes could be employed to promote engagement with green areas and nature-oriented attitude.

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Table 1. Summary of key hypotheses for the relationship between green space and the dependent variable, health.

Explanatory Variable	**Expected effect on health**
Green Space	Improves health (De Vries *et al*. 2003; Mitchell et al. 2007; Maas *et al*. 2009 ; Sandifer et al. 2015 ; Frumkin et al. 2017); one possible pathway could be through lowering mortality from circulatory diseases by increasing levels of physical activity (Mitchell and Popham 2008 ; Blair and Morris 2009), and reducing stress (Albus 2010), noise and air pollution exposure (Gold and Mittleman 2013). Another possible pathway could be through regulating immune function with environmental microorganisms that diversify human microbiomes (Flies et al. 2017). Walkable green spaces – linked to physical activity (James et al. 2015) – could also positively influence the longevity of residents (Richardson et al. 2013). Also improves birth and developmental outcomes by increasing maternal levels of physical activity, and reducing maternal stress, noise and air pollution exposure (Dadvand et al. 2012).
Wealth	Improves health (Deaton 2002; Pollack *et al*. 2007).
Population Density	Densely populated environments decrease health (Schmitt 1966; Tanaka 1996; Gray 2001)
Natural Assets	Improve health (Heerwagen 1990; Laumann *et al*. 2001)
Pollution	Decreases health (Moore *et al*. 2003; Rydin *et al*. 2012)
Sunshine	Improves health (Mead 2008), though excess sunshine may decrease health (Lucas et al. 2006).
Stability	Improves health (Stafford *et al*. 2007; Corburn 2009)
Healthcare	Improves health (Takano and Nakamura 2001; Wilkinson and Marmot 2003)
Culture and Environment	Improves health (van Kamp et al. 2003)
Education	Improves health (Ross and Wu 1995; Deaton 2002)
Infrastructure	Improves health (Wilkinson and Marmot 2003; Galea *et al.* 2005)
GDP per capita	Improves health (Swift 2011)

Table 2. Standardised regression coefficients and AICc values for top 10 models predicting health for total sample of cities (n=34).

The coefficients with their 95% confidence intervals (in parentheses) not overlapping with zero are shown in bold.

Intercept	Green space	Wealth	Green space × Wealth	Natural assets	Population density	Sunshine	AICc	Δ_i
0.608	**-0.134 (± 0.131)**	**0.718 (± 0.138)**	**0.374 (± 0.255)**				37.004	0
0.609	**-0.143 (± 0.130)**	**0.715 (± 0.137)**	**0.341 (± 0.258)**			-0.0816 (± 0.129)	38.204	1.200
0.608	**-0.142 (± 0.134)**	**0.713 (± 0.140)**	**0.364 (± 0.260)**	-0.0399 (± 0.131)			39.559	2.555
0.610	**-0.139 (± 0.135)**	**0.727 (± 0.148)**	**0.333 (± 0.331)**		0.0376 (± 0.188)		39.794	2.790
0.610	**-0.149 (± 0.134)**	**0.711 (± 0.139)**	**0.333 (± 0.263)**	-0.0343 (± 0.131)		-0.0792 (± 0.131)	41.080	4.076
0.624	**-0.179 (± 0.135)**	**0.715 (± 0.154)**			**0.156 (± 0.154)**		41.104	4.100
0.611	**-0.147 (± 0.134)**	**0.724 (± 0.147)**	0.305 (± 0.331)		0.0332 (± 0.187)	-0.0807 (± 0.131)	41.254	4.250
0.624	**-0.184 (± 0.133)**	**0.712 (± 0.152)**			0.138 (± 0.154)	-0.0970 (± 0.134)	41.801	4.797
0.624	**-0.186 (± 0.137)**	**0.645 (± 0.137)**				-0.116 (± 0.137)	42.307	5.303
0.624	**-0.180 (± 0.141)**	**0.639 (± 0.141)**					42.502	5.498

Figure caption

Fig. 1. Global examples of urban green spaces: (a) protected area – Tijuca Forest National Park, Rio de Janeiro; (b) open recreational field – Galle Face Green, Colombo; (c) city park – Fuchunomori Park, Tokyo; and (d) wayside trees and shrubs – Pasir Ris Town, Singapore (Photos a, b and d: KSHP; photo c: TA).

Fig.2. Maps of the 34 cities used in the analysis, where the size of each circle related to (a) square-root green space (m^2 per inhabitant) and (b) the LSE Cities Health Index.

Fig.3. Relationship between green space (m^2 per inhabitant) and health (logit-transformed) in four groups of cities categorised based on the wealth index: nine cities with the wealth index <0.57 (1st quantile) shown with red triangles and a dash-dotted regression line, eight cities ≥0.57 and <0.66 (median) with orange diamonds and a dashed line, eight cities ≥0.66 and <0.77 (3rd quartile) with blue squares and a dotted line, and nine cities ≥0.77 with dark blue circles and a solid line. Regression lines are based on coefficients of the best linear regression model in Table 2. City codes relate to city names (see Table S2).

Fig. 1

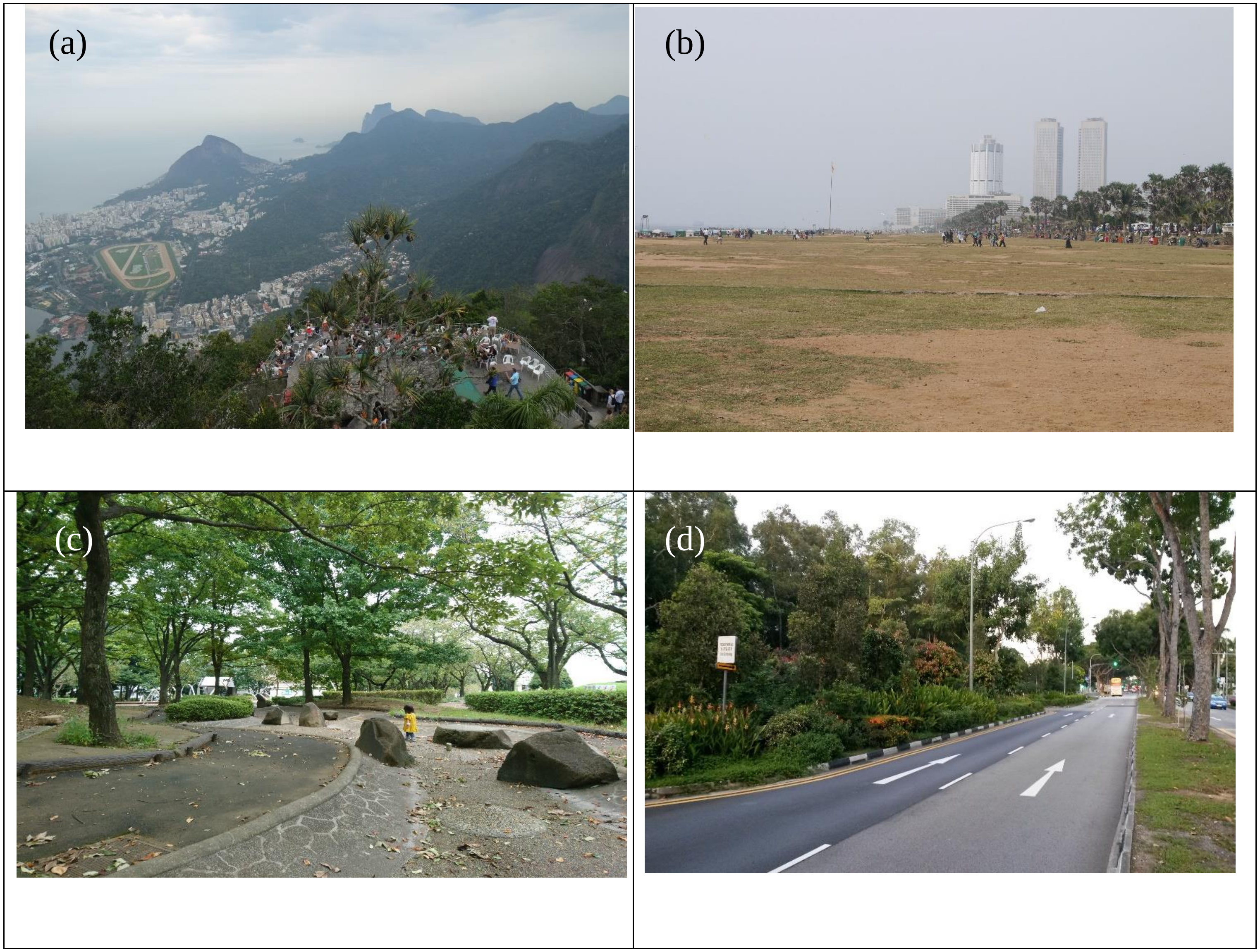


Fig. 2

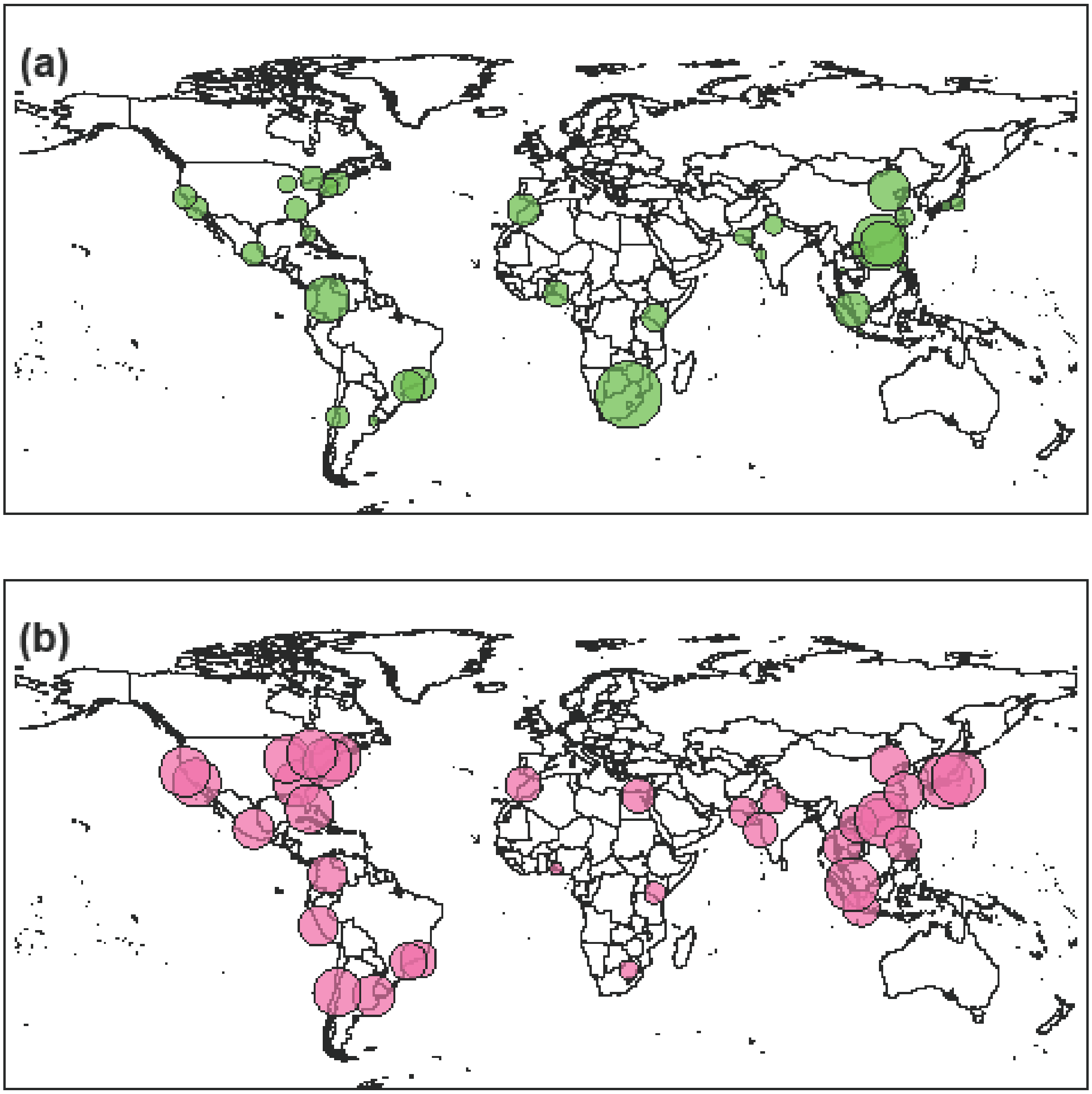
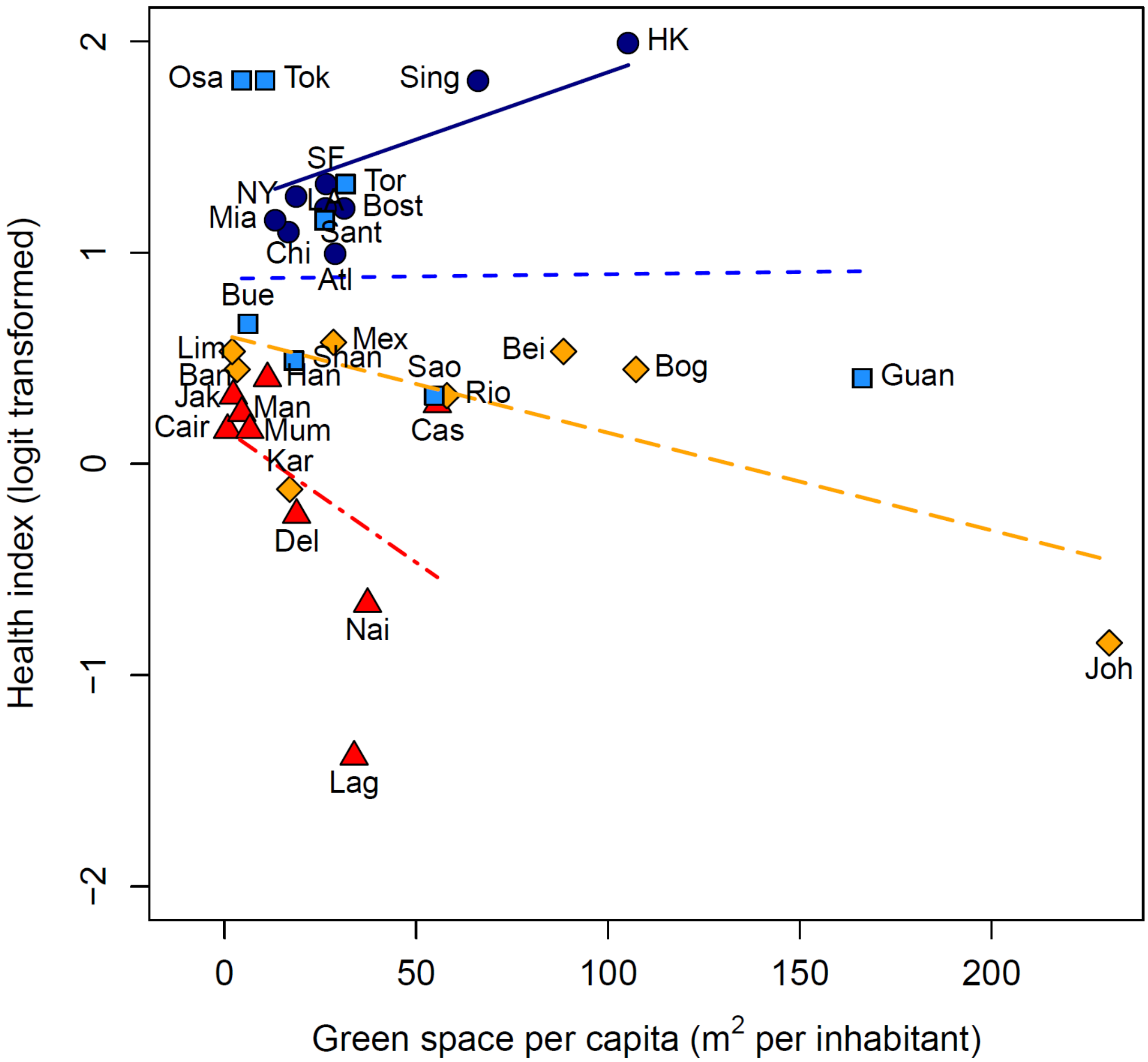


Fig. 3



HK
Osa
Tok
Sing
SF
Tor
NY
LA
Bost
Mia
Sant
Chi
Atl
Bue
Mex
Lim
Shan
Bei
Sao
Bog
Guan
Ban
Han
Rio
Jak
Man
Cair
Mum
Cas
Kar
Del
Nai
Joh
Lag
Health index (logit transformed)
2
1
0
−1
−2
0
50
100
150
200
Green space per capita (m2 per inhabitant)

Supporting Information

Table S1. Pearson's correlation coefficients among explanatory variables considered (|r| > 0. 65 shown in bold).

	Green space	Wealth index	Population density	Natural assets	Pollution	Sunshine	Stability	Healthcare	Culture and environment	Education	Infrastructure
Green space											
Wealth index	0.053										
Population density	-0.028	-0.393									
Natural assets	-0.173	-0.142	-0.11								
Pollution	0.119	**-0.676**	0.638	0.168							
Sunshine	-0.045	-0.214	0.006	0.146	0.144						
Stability	-0.004	**0.742**	-0.47	0.083	-0.567	-0.169					
Healthcare	-0.095	**0.883**	-0.516	-0.166	**-0.765**	-0.289	**0.781**				
Culture and environment	0.082	**0.777**	-0.621	-0.166	**-0.8**	-0.252	**0.659**	**0.868**			
Education	-0.074	**0.788**	-0.626	-0.189	**-0.792**	-0.19	**0.685**	**0.887**	**0.855**		
Infrastructure	0.06	**0.85**	-0.477	-0.039	**-0.708**	-0.248	**0.814**	**0.869**	**0.838**	**0.756**	
GDP per capita	-0.021	**0.901**	-0.504	-0.293	**-0.704**	-0.031	0.616	**0.783**	**0.684**	**0.733**	**0.794**

Table S2. Data with city codes, associated cities and wealth groups (1: wealth index <0.57 [1st quantile]; 2: wealth index ≥0.57 and <0.66 [median]; 3: wealth index ≥0.66 and <0.77 [3rd quantile]; and 4: wealth index ≥0.77).

City	Green_space	Natural_Assets	Pop_Density	Health_index	Wealth_index	Sunshine	Code	Wealth_Group
Atlanta	28.9	4	1090	0.73	0.78	2738.3	Atl	4
Bangkok	3.3	3.7	5643	0.61	0.63	2623.8	Ban	2
Beijing	88.4	3.7	6544	0.63	0.65	2748.5	Bei	2
Bogota	107.3	1.3	19915	0.61	0.62	1328	Bog	2
Boston	31.2	2.7	1828	0.77	0.79	2633.6	Bost	4
Buenos Aires	6.1	4	5650	0.66	0.67	1787.2	Bue	3
Cairo	0.8	3.7	20152	0.54	0.54	3451	Cair	1
Casablanca	55.5	4	11947	0.57	0.53	2927.4	Cas	1
Chicago	16.6	3.3	2399	0.75	0.78	2508.4	Chi	4
Guangzhou	166.3	3.3	8395	0.6	0.67	1773.2	Guan	3
Hanoi	11.2	1.7	16739	0.6	0.50	1466.1	Han	1
Hong Kong	105.3	1.3	25933	0.88	0.77	1835.6	HK	4
Jakarta	2.3	3.3	13853	0.58	0.51	2956.5	Jak	1
Johannesburg	230.7	2.7	4499	0.3	0.62	3124.4	Joh	2
Karachi	17	1.7	29233	0.47	0.60	2950.3	Kar	2
Lagos	33.8	4	13100	0.2	0.46	1845.4	Lag	1
Lima	2	3.7	12900	0.63	0.63	1230	Lim	2
Los Angeles	26.3	2	2580	0.77	0.78	3254.2	LA	4
Manila	4.5	2	20081	0.56	0.55	2103.1	Man	1
Mexico City	28.4	1.7	8388	0.64	0.64	2211.5	Mex	2
Miami	13.2	3.7	1717	0.76	0.77	3154	Mia	4
Mumbai	6.6	3.3	28979	0.54	0.56	2583.5	Mum	1
Nairobi	37.3	2.7	6039	0.34	0.44	2482	Nai	1
New Delhi	18.8	3.7	13088	0.44	0.56	2684.6	Del	1
New York	18.7	2.3	2744	0.78	0.79	2534.7	NY	4
Osaka	4.5	2.7	6474	0.86	0.73	1996.5	Osa	3
Rio de Janeiro	58	1.3	6819	0.58	0.64	2078.5	Rio	2
San Francisco	26.5	1.3	2820	0.79	0.80	3061.7	SF	4
Santiago	26.1	3.3	7871	0.76	0.66	2462	Sant	3
Sao Paulo	54.7	2.7	8974	0.58	0.67	1732.7	Sao	3
Shanghai	18.1	4	6415	0.62	0.67	1977.8	Shan	3
Singapore	66.2	4	13398	0.86	0.78	2022.4	Sing	4
Tokyo	10.6	3.3	5752	0.86	0.74	1876.7	Tok	3
Toronto	31.6	4	3156	0.79	0.76	2066.3	Tor	3