Health & Place 72 (2021) 102690

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

Neighbourhood green space and health disparities in the global South: Evidence from Cali, Colombia

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ARTICLE INFO

Keywords:
Green space
Health disparities
Inequalities
Physical activity
Global South
Colombia
Cali

ABSTRACT

Increasing attention has been given to the role of green space in reducing health disparities. However, robust evidence to support decision making is lacking in the global South. We investigate the relationship between green space and health as well as its underlying mechanism in Cali, Colombia. Results indicate that neighbourhood greenness is associated with enhanced self-rated 'good' health and reduced physical and mental distress. The health benefits of green space appear to be stronger for people living in wealthier neighbourhoods than those in poor neighbourhoods. Results highlight the importance of considering health disparities for future green infrastructure planning in the global South context.

1. Introduction

Much of the urbanisation taking place in the global South is haphazard, with urban population growing at a faster rate than governments can plan and manage. Although urbanisation is expected to bring some opportunities, urban environments inherently pose practical and logistical challenges to maintaining and improving health and wellbeing in low- and middle-income countries (UNICEF, 2018). Rapid urbanisation in the developing context often leads to crowded, unplanned living environments that do not allow for the creation and maintenance of open and green spaces. Excessive urbanisation without proper mitigation strategies may exacerbate living conditions of low-income families, making them to live near open sewers and heavy traffic, and therefore being disproportionately exposed to unhealthy environmental hazards (Moore et al., 2003). Especially in the context of the global South, people who need the most in terms of health-promoting urban environments are often the ones living in areas lacking investments in healthy environments (Rigolon et al., 2021).

As a way to address health disparities, both European Commission and World Health Organization have been advocating for sustainable and equitable urban developments through provision of accessible green spaces and green infrastructure (European Commission, 2015; WHO, 2016). While green space and green infrastructure are slightly different terms (Taylor and Hochuli, 2017), we use them interchangeably in this research to describe both maintained and unmaintained vegetated areas, including trees, parks, gardens, nature reserves in urban environments. For the past several years, increasing attention has been placed on the health benefits of green space (Twohig-Bennett and Jones, 2018), especially in addressing chronic illnesses and psychological conditions (Frumkin, 2013). Evidence has been accumulating on the specific health benefits of green space – for example, lower mortality rates (Donovan et al., 2013), enhanced well-being (Sugiyama and Thompson, 2007), and improved mental health outcomes (Astell-Burt and Feng, 2019; Nutsford et al., 2013; Ward Thompson et al., 2012). Furthermore, green space has been linked to health through promotion of healthy behaviours, such as walking, cycling, and green exercise (Bedimo-Rung et al., 2005; Kaczynski et al., 2016; Maas et al., 2009; Nielsen and Hansen, 2007). Access to open space and parks has been shown to promote physical activity across different segments of the population, and has the potential to reduce health disparities based on socioeconomic status (Mitchell and Popham, 2008).

Most of the research on green space and health to date has been conducted in high-income countries in the global North, lacking robust evidence to support decision making in the global South. Although an

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https://doi.org/10.1016/j.healthplace.2021.102690
Received 22 March 2021; Received in revised form 23 September 2021; Accepted 4 October 2021

increase in supplies of green space would lead to improved health at the population level, it is unclear whether such benefits would be shared equitably in the global South context (Wolch et al., 2014). Several studies have shown that cities in the global North might have been in different trajectories in terms of social and income inequalities in green space access and their implications for health (Jones et al., 2009; Kabisch et al., 2016; Mitchell and Popham, 2008). In contrast, there seem to be more pronounced socioeconomic inequalities in green space access, especially proximity, in the global South (Rigolon et al., 2018). This implies that there could be important distinctions between the global North and the global South in terms of green space-related health disparities and the mechanisms underlying them. Furthermore, various mechanisms linking green space to health, such as physical activity and air pollution, have been explored in the context of global North, but empirical evidence supporting these hypotheses is still limited in the global South (Markevych et al., 2017).

To fill this important research gap, this study investigated the relationship between green space and health disparities – specifically, general health status, and physical and mental distress – and examined whether physical activity could be an underlying mechanism linking this relationship in Cali, Colombia. This study leverages the on-going city-wide survey which provided valuable information on a number of health dimensions, ranging from quality of life to physical and mental health conditions of Cali residents. The uniqueness of this study comes from expanding the research in a city with highly unequal health outcomes across the socioeconomic strata (Martínez, 2021). We also addressed the current data challenges in the global South by taking advantage of high-resolution satellite data to create a linked geospatial database that allows for answering a number of policy-related questions. Given the paucity of green space and health research in the global South, this study provides important insights into our understanding of green space and health disparities in Colombia, and provides a catalyst for other researchers to explore the critical health equity issues related to green space in the global South context.

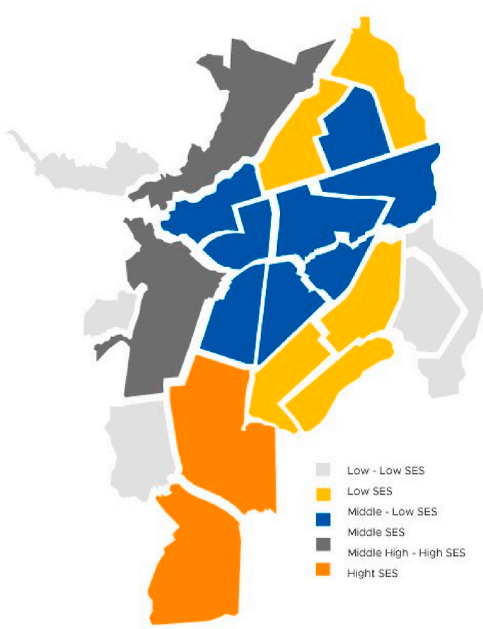
2. Data and methods

2.1. Study area

Our study area was the city of Cali, which is the third largest city in Colombia with 2.4 million population (DANE, 2019). As with many other cities in the global South, Cali has experienced an important process of urbanization and population growth over the last decades. By 1993, Cali had 1.6 million population (DANE, 2019), adding nearly one million habitants over 20 years. As shown in Fig. 1, most of the public spending in city infrastructure, parks, and green space is concentrated along the North-South corridor where high-income neighbourhoods are mostly located. For instance, green areas (parks, forest, and public space) are concentrated in the most affluent districts. In total, by 2019, the tree counting in the city was 291.550, with 0.12 planted trees per habitant, with important differences by districts' socioeconomic conditions. Districts with lower SES, had on average 0.03 trees per habitant, whereas high income districts had 1.12 trees per habitant (de Cali Alcaldía, 2019). During the last two electoral terms, there has been important investments to promote physical activity in public spaces. This program also compliments the existing CicloVida program, which closes public roads every Sundays to promote walking and cycling. Although recent evidence suggests potential health benefits of these policy interventions (Gómez et al., 2015), the emerging issues of health disparities in relation to green spaces remain unknown.

2.2. CaliBRANDO survey

We used data from CaliBRANDO, an annual city-wide survey collected since 2014 in Cali. CaliBRANDO is designed, collected, and fully financed by Universidad Icesi through the Observatory of Public Policy (Martínez, 2017). The main objective of the survey is to measure and track subjective well-being in the city. The survey is statistically representative by gender, socioeconomic strata, and race/ethnicity, with an average 2.8% margin of error and a confidence level of 95% compared to the city-wide population statistics. For this study, we used a two-year combined dataset with matching geocoded residential information (2017–2018), yielding the sample size of 2,475 participants. After spatially linking the survey data with the green space data (described shortly after), the total sample size came down to 2,406 participants (2.7% unmatched due to missing residential information). For the original data collection, we used a stratified random sampling to achieve a representative sample of the city-wide population. Data were collected in June 2017 and June 2018 by trained pollsters using face-to-face interviews at 36 central points (bus stations, parks, public



NSE	Population (2018)*	Public transport stations (MIO) (2018)***	Health centers (2016)	Homicides per 100,000 inhabitants (2018)*	Effective public space per 100,000 inhabitants (2018)**	Public space for sports and recreation per 100,000 inhabitants (2018)**
	606445	8	34	397	1,58	15,82
	704960	11	48	389	1,83	26,36
	666115	26	66	270	1,37	22,45
	236380	8	311	37	4,78	18,2
	149475	8	16	31	9,66	30,04
	12044	2	6	6	44,08	58,48

* Mayor of Santiago de Cali
** Public space policy
*** Metro Cali

Fig. 1. Access to public services and crime by district socioeconomic conditions.

spaces, malls and points with large public concentration) distributed across the city, and covering the 22 city districts. Respondents were adults aged 18 years and older living in the city who were selected randomly at each central point. Respondents were approached and explained the purpose of the study, assuring confidentiality. As participation was voluntary, the respondents could stop the survey at any time. Each survey competition took about 25 min. No personally-identifiable information, such as names, ID, or phone number, was collected.

2.3. Health outcomes

For this analysis we used four self-reported health variables: general health status, physical distress, mental distress, and physical activity. The general health, physical distress, and mental distress variables were taken by the protocol designed by the Centers for Disease Control and Prevention (CDC) for measuring “healthy days” (CDC, 2018). These measures are commonly used in large population-based health surveys and surveillance, such as the National Health and Nutrition Examination Survey (NHANES) and the Behavioral Risk Factor Surveillance System (BRFSS), as a population assessment of health-related quality of life (HRQOL). Research has shown that these measures are valid and reliable in various population groups (Andresen et al., 2003; Hennessy et al., 1994; Moriarty et al., 2003; Zullig et al., 2004).

To measure “general health” respondents were asked: “Would you say that in general your health is excellent, very good, good, fair, or poor?” With this question we created a dummy variable “self-rated good health” taking the value of 1 when respondents declare to have “good”, “very good”, or “excellent”, and 0 otherwise. Similar measurement and operationalization methods have been used previously in the context of health disparities and natural environments (Mitchell and Popham, 2007; Wheeler et al., 2012). For a robustness check, we also tested results using different dichotomization thresholds, indicating 1 for “very good” and “excellent”, and 0 otherwise. For physical distress, respondents were asked: “Now thinking about your physical health, which includes physical illness and injury, for how many days during the past 30 days was your physical health not good?" For the mental distress measure, we used the question: “Now thinking about your mental health, which includes stress, depression, and problems with emotions, for how many days during the past 30 days was your mental health not good?” We created a dummy variable for physical distress and mental distress indicating 1 if the number of days reporting physical or mental distress was more than or equal than 14 days. Health practitioners use the same cut-off period (14 days) to diagnose mood disorders (Brown et al., 2003). Lastly, the variable to measure physical activity and exercise levels was based on the questionnaire: “Do you engage in any physical activity in the week such as jogging, walking, playing a sport, or going to the gym?”. This variable was also constructed as a dichotomous variable, 1 taking the value of “yes”, 0 otherwise.

2.4. Neighbourhood greenness

Green space exposure generally implies the availability of green space near the home, but no standardised definition for this exposure proxy exists (Markevych et al., 2017). We used remote sensing data to quantify a proxy measure for neighbourhood greenness using the normalised difference vegetation index (NDVI) (Tucker, 1979). Chlorophyll is easily detectable from multispectral imagery using the visible red (R) and near-infrared bands (NIR), and the NDVI is calculated as the difference between the NIR and R bands divided by their sum (Weier and Herring, 2000). NDVI values can vary between −1 and 1 – values close to 0 mean that there is no vegetation at all, and values close to 1 indicate the highest possible density of green leaves (Weier and Herring, 2000).

The NDVI has been shown to be a useful metric to study associations between green space and health outcomes worldwide (Dadvand et al., 2012; WHO, 2016). Especially, in a tropical city like Cali with abundant trees and natural habitats, the NDVI measure would be a good proxy for green space availability. Unlike specific geospatial measures, such as distance to parks or size of public gardens, NDVI captures more comprehensive aspects of ecosystem services that offer health-related environmental benefits, such as reduction in noise, surface temperature, and air pollution (Meerow and Newell, 2017), all of which may not be easily measured using traditional vector-based geospatial data.

For the NDVI calculation, we used a cloud-free PlanetScope Analytic Ortho Tile image acquired on 2018-08-11 (©2019 Planet Labs) with a spatial resolution of 3 m to extract NDVI values by neighbourhood (Fig. 2). This satellite product was already processed to remove geometric distortions caused by terrain and was applied radiometric corrections to correct for sensor artefacts and to transform to at-sensor-radiance. We used the city’s neighbourhood boundaries or barrios, the smallest subdivisions for which census data are collected, to obtain the centroids of each neighbourhood and calculate buffer distances for estimating green space exposure. Given our focus on physical activity, we used 400 m as our primary buffer distance because it approximates a typical 5-min walking distance frequently used by urban planners (Perry, 1929). To test the sensitivity of our results, other buffer sizes were also examined and presented in supplementary materials. The satellite data processing and the NDVI value calculation were done in R 3.5 and Python 3.5.

2.5. Covariates

A number of research has shown that the relationship between natural outdoor environments and health could vary by sex (Astell-Burt et al., 2014; Reklaitiene et al., 2014; Richardson and Mitchell, 2010; Tamosiunas et al., 2014), age (Cervinka et al., 2012; Haluza et al., 2014; Wyles et al., 2019), and socioeconomic status (Dadvand et al., 2014; de Vries et al., 2003; Maas, 2006; Mitchell and Popham, 2007, 2008). Therefore, we included these factors as our covariates. In Colombia, households are classified on a socioeconomic scale from one (poorest) to six (richest). This strata classification is also used to classify neighbourhoods and districts. In Cali, about 50% of the population lives in the neighbourhoods in the lowest socioeconomic strata, and about 40% are classified as middle class under the government household-socioeconomic classification. Less than 10% are in the more affluent households (DAPM, 2018).

2.6. Analytical approach

Generalised mixed effects models were fitted to estimate the effects of neighbourhood greenness on three self-reported health outcomes described earlier. Because each survey participant is nested within barrios (a common neighbourhood unit), we used barrios as a random cluster variable to capture the multi-level structure of the data. To understand potential heterogenous effects across subgroups, we also developed models stratified by age, sex, and socioeconomic status. All coefficients were reported in the unit of one interquartile range (IQR) change of NDVI. Additional path analyses were performed to examine whether physical activity mediates the relationship between neighbourhood greenness and the three health outcomes. We applied a bootstrap technique with 10,000 iterations to examine indirect effects mediated through physical activity. Unlike the mixed effects models, the mediation analysis did not account for random intercepts. Mediation was conducted in R using the lavaan package (Rosseel, 2012), and standardised coefficients were used to allow comparison of both direct and indirect effects.

3. Results

3.1. Descriptive results

In terms of the general characteristics of our sample (Table 1), the

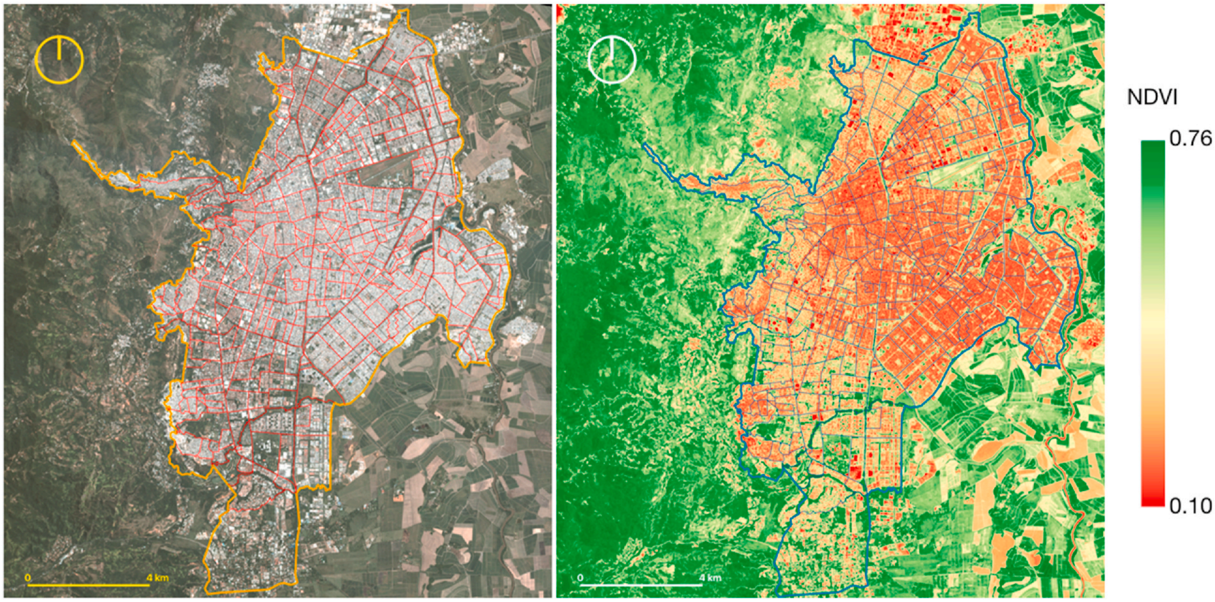


Fig. 2. Original PlanetScope satellite image (left) and the calculated NDVI over the urban area of Cali with its neighbourhood boundaries (right).

Table 1
Descriptive summary ($n = 2406$).

Variables	Our Sample	City of Cali*
	Mean (SD) or N (%)	Mean (SD) or N (%)
Age[a]	38 (±15)	35
Sex		
Female	1203 (50.00%)	51%
Male	1203 (50.00%)	49%
Socioeconomic status[b]		
Low	954 (39.65%)	42%
Medium-low	246 (10.22%)	7%
Medium-high	760 (31.59%)	34%
High	429 (17.83%)	17%
Neighbourhood greenness		
NDVI (mean)	0.30 (±0.06)	0.28[g]
NDVI (≤100 m)	0.29 (±0.08)	–
NDVI (≤200 m)	0.29 (±0.07)	–
NDVI (≤300 m)	0.29 (±0.06)	–
NDVI (≤400 m)	0.30 (±0.06)	–
NDVI (≤500 m)	0.31 (±0.07)	–
NDVI (≤1 km)	0.33 (±0.07)	–
Self-reported health outcomes		
Self-rated good health (≥good)[c]	1995 (82.92%)	–
Frequent physical distress (>14 days)[d]	167 (6.94%)	–
Frequent mental distress (>14 days)[e]	117 (4.86%)	–
Weekly physical activity[f]	1253 (52.08%)	–

Note. Percentages may not add up to 100% due to rounding and missing data. Missing data are reported here.
*Information taken from: Departamento Administrativo de Planeación.
[a] 4 missing data.
[b] 17 missing data.
[c] 4 missing data.
[d] 1 missing.
[e] 3 missing data.
[f] 1 missing data.
[g] Values obtained from Florczyk et al. (2015).

average age was 38 (SD = 15), which is older than the general population of the city (city-wide average is 35 years old). The sample is well balanced by sex, and other demographic characteristics generally follow the city-wide population profile, making it a representative sample of Cali.

The average value of the neighbourhood greenness measure (NDVI) was 0.3, with the range varying between 0.15 and 0.63 depending on the circular buffers being used. This value is similar to the city-wide average NDVI of 0.28 reported in other satellite dataset (Florczyk et al., 2015). For the health outcomes, 83% of the participants rated their health as good or better (scores of 3–5 out of the total score of 5). About 6.9% reported frequent physical distress for more than 14 days, and 4.9% reported mental distress for more than 14 days. The percentage of mental distress is lower than what's reported in other places; however, this is somewhat common in Colombia where reported mental health problem is generally low for cultural reasons and due to limitations in the health system which made it difficult to measure and treat those conditions (Fandiño-Losada et al., 2017). About 52% of the study participants reported that they engage in any physical activity on a weekly basis.

3.2. *Relationship between green space and health*

Table 2 shows the model results for the three health outcomes under study. For self-rated good health, an increase in the interquartile range (IQR) of neighbourhood greenness (NDVI ≤400 m) was associated with an increase in the adjusted odd ratio (OR = 1.23, 95% CI = 1.04–1.45). Odd ratio for physical distress in relation to an IQR increase in neighbourhood greenness was 0.76 (95% CI = 0.59–0.97). No significant relationship was found between an IQR increase in neighbourhood greenness and mental distress (OR = 0.97, 95% CI = 0.74–1.27). However, given that this pattern was consistent with other measures, it is possible that there might not be enough power to detect a real effect.

The results using all other buffer sizes can be found in Table S1 in the supplementary material. For self-rated general health, the association was relatively larger with the buffer size of 200 m. For physical and mental distress, the peak association was with the 400 m buffer size. We also checked robustness of the results using different cut-off of the self-rated health measure (1 = very good and excellent; 0 = otherwise). The results were similar but with a slight attenuation of association (Table S2).

Coefficients of the covariates were all in the expected direction. A one-year increase in age was associated with a decrease in the adjusted odd ratio for self-reported good health (OR = 0.97, 95% CI = 0.97–0.98), and an increase in the odd ratios for physical and mental

Table 2
Adjusted odd ratios of three health outcomes attributable to an increase in the interquartile range (IQR) of neighbourhood greenness (NDVI ≤400 m).

	Model 1: self-rated good health (≥good)	Model 2: physical distress (>14 days)	Model 3: mental distress (>14 days)
	OR (95% CI)	OR (95% CI)	OR (95% CI)
Neighbourhood greenness (NDVI ≤ 400 m)	1.23 [c] (1.04, 1.45)	0.76 [c] (0.59, 0.97)	0.97 (0.74, 1.27)
Age	0.97 [a] (0.97, 0.98)	1.03 [a] (1.02, 1.05)	1.00 (0.99, 1.01)
Sex (Female = 1)	0.62 [a] (0.49, 0.77)	1.49 [b] (1.07, 2.06)	1.75 [c] (1.19, 2.59)
SES (Middle to High = 1)	1.26 (0.99, 1.60)	0.97 (0.67, 1.41)	1.03 (0.68, 1.57)
Random effects			
σ^2	3.29	3.29	3.29
τ_{00}	0.05_{barrio}	0.20_{barrio}	0.23_{barrio}
ICC	0.01	0.06	0.07
N (barrios)	264	264	264
Goodness-of-fit			
AIC	2091.90	1160.90	921.87
BIC	2126.56	1195.55	956.52
Observations	2381	2384	2382

All models are adjusted for age, sex, and socioeconomic status. Odds ratios are all calculated on interquartile range (IQR) scale. Model 1 has 25 missing data; Model 2 has 22 missing data; and Model 3 has 24 missing data.
[a] $p < 0.001$.
[b] $p < 0.01$.
[c] $p < 0.05$.

distress. Being female was also associated with a decrease in the odd ratio for self-reported good health (OR = 0.62, 95% CI = 0.49–0.77), and increased odd ratios for physical and mental distress. Living in mid- to high-SES neighbourhoods was positively correlated with self-reported health (OR = 1.26, 95% CI = 0.99–1.60); however, the coefficient was not statistically significant at the 5% level.

3.3. Health disparities by age, sex, and socioeconomic status

Fig. 3 shows the results of the association between neighbourhood greenness and self-rated good health, stratified by age, sex, and socioeconomic status. When looking at the age-stratified results, the effect size was larger for the participants aged 60 and over (OR = 1.46, 95% CI = 0.93–2.29) than the participants aged below 60 (OR = 1.21, 95% CI = 1.01–1.42), but the coefficient was not statistically significant at the 5% level. It is possible that we had not have enough power to detect an effect in this subgroup because of a smaller sample size of the older adult subgroup (n = 223) compared to the younger subgroup (n = 2,158).

The sex-stratified model result showed that the effect size was similar for male (OR = 1.24, 95% CI = 0.95–1.62) and female (OR = 1.22, 95% CI = 1.01–1.51). An increase in the IQR of neighbourhood greenness (NDVI ≤400 m) was strongly associated with increased self-rated good health for the participants living in neighbourhoods with mid- to high-socioeconomic status (OR = 1.46, 95% CI = 1.14–1.86), but the association attenuated for people living in neighbourhoods with low socioeconomic status (OR = 1.02, 95% CI = 0.83–1.26).

3.4. Physical activity as a mediating factor in health disparities

Fig. 4 shows the results of the path models that examined the mediating role of physical activity. Like the previous models, all models were adjusted for age, sex, and socioeconomic status. Note that due to the limitation of the structural equation modelling package (lavaan), the data were fitted using a probit link function, instead of the logit link function. Thus, the parameter estimates were point estimates, not odd ratios.

Overall, there was strong support for the partial mediation effect of physical activity for self-rated good health and physical distress, but not for mental distress. When looking at the standardised coefficients for self-rated good health (Fig. 4a), an IQR increase in neighbourhood greenness (NDVI ≤400 m) was associated with an increase in physical activity (β = 0.063, $p < 0.001$). There was also a significant positive association between physical activity and self-rated good health (β = 0.033, $p < 0.05$). The association between an IQR increase in neighbourhood greenness (NDVI ≤400 m) and self-rated good health was partially mediated through physical activity (β = 0.024, $p < 0.05$), explaining about 7.6% of the total effect.

Regarding physical distress using standardised coefficients (Fig. 4b), physical activity was negatively associated with physical distress (β = -0.425, p = 0.11). The total effect of an IQR increase in neighbourhood greenness (NDVI ≤400 m) on physical distress was −0.329 ($p < 0.05$), and this effect was partially mediated through physical activity, explaining 7.7% of the total effect. For mental distress, the mediation

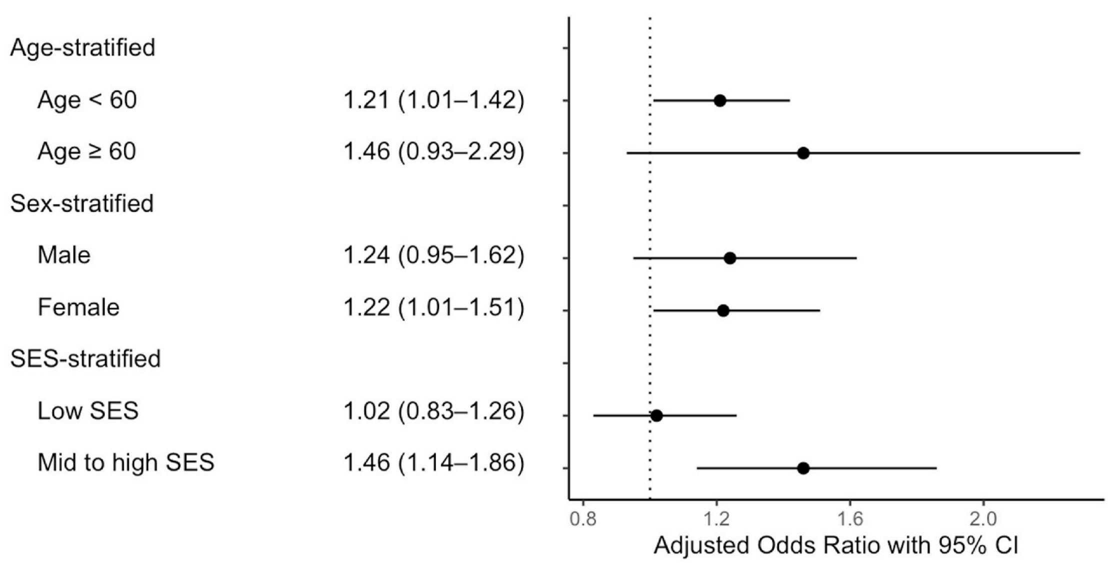


Fig. 3. Adjusted odd ratios of self-rated good health in relation to an interquartile range (IQR) increase in neighbourhood greenness (NDVI ≤400 m), stratified by age, sex, and socioeconomic status (SES). Note. The line around the dot indicates 95% confidence interval; Age-stratified model is adjusted for sex and SES; sex-stratified model is adjusted for age and SES; SES-stratified model is adjusted for age and sex.

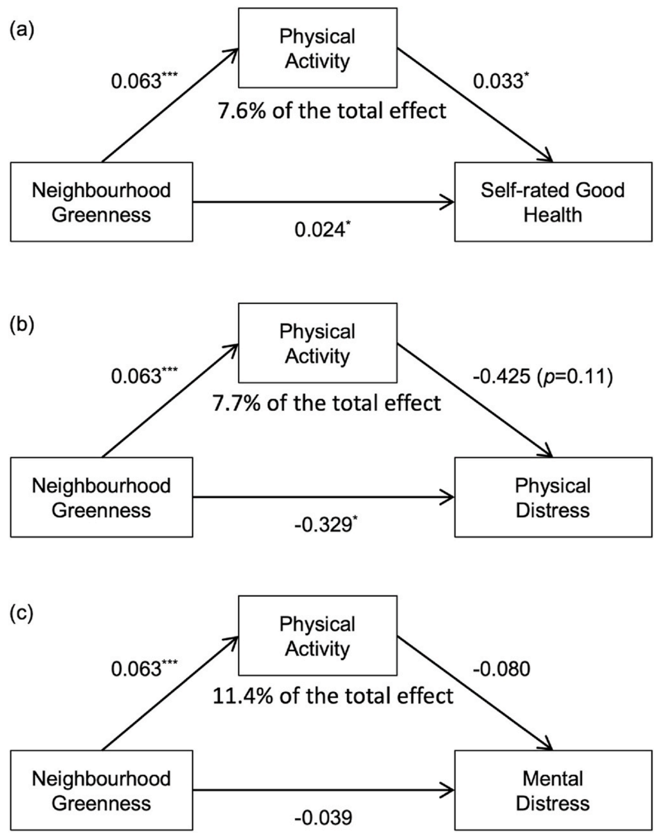


Fig. 4. Mediating role of physical activity on the relationships between an interquartile range (IQR) increase in neighbourhood greenness (NDVI ≤400 m) and (a) self-rated good health; (b) physical distress; and (c) mental distress. *Note.* ***p < 0.001; **p < 0.01; *p < 0.05 All models are adjusted for age, sex, and socioeconomic status. The models were fitted using a Probit link function.

effect of physical activity trended in the expected direction (β = -0.080), but the association was not statistically significant at the 5% level.

4. Discussion

In this study, neighbourhood greenness was positively associated with self-rated good health and negatively associated with physical distress in Cali, Colombia. This finding is consistent with the results of previous studies from high-income countries on the association between green space and self-reported health outcomes (Dadvand et al., 2016; Kondo et al., 2018; Maas, 2006; van den Berg et al., 2015). In particular, our study showed that the association between green space and self-rated health was larger than what has been previously reported in high-income countries. For example, in Barcelona, Spain, Dadvand and his colleagues (2016) reported that the odds ratio of self-rated good health (≥good) associated with an interquartile range increase in NDVI of 500 m buffer was 1.16 (95% CI = 1.05–1.29), which is comparable but smaller than estimates found in our study (OR = 1.23, 95% CI = 1.04–1.45, NDVI ≤400 m). Despite some similarities, it would be difficult to interpret our findings based on studies conducted in high-income countries due to substantial differences in cultural, political, and economic contexts. It is possible that our results represent missed opportunities in maximizing health benefits by providing more green spaces in Colombia. Further longitudinal studies would be needed to confirm the potential associations presented in this study.

Although the research base is small, there have been accumulation of evidence suggesting similar associations between green space and health in low- and middle-income countries. In a study of older adults living in Kaunas City, Lithuania, older women who used park had higher odds of having poor general health and depressive symptoms if they lived more than 300 m away compared to those who lived within 300 m of nearest park (Reklaitiene et al., 2014). Another study conducted in Delhi, India found an inverse relationship between exposure to the largest nearest park areas (within 1 km buffer of participant's home) and major depression (Mukherjee et al., 2017). Our study adds further evidence that similar positive health effects of green space exist in low- and middle-income countries as well as high-income countries. On the other hand, we found attenuation of association between green space and mental distress. This is somewhat unexpected as mental health benefits of green spaces are well documented (van den Berg et al., 2015). One explanation is that in our sample the prevalence of mental distress was lower (4.86%) than other health outcomes (e.g. physical distress = 6.94%), so we may not have had enough power to detect an effect. It is also possible that our measure of mental distress may not capture the full aspect of mental health and depression, suggesting that further research using different measures of psychological distress would be useful (Batterham et al., 2018).

Our study results highlighted some contextual differences in health disparities in green space access between the global North and the global South. Previous research showed that no clear differences were observed for income or race-related inequalities in green space access in the global North (Barbosa et al., 2007; Wolch et al., 2014). Several studies conducted in the UK found that people living in more deprived areas even had greater access to green space (Barbosa et al., 2007; Jones et al., 2009) and less income-related health inequalities (Mitchell and Popham, 2008). This highlights the potential of using green space as an effective strategy to reduce health disparities. However, there seem to be more consistent inequalities in green space access in the global South (Rigolon et al., 2018). A recent panel study from South Africa showed that middle-income group had more positive health effects of living in a greener environment compared to low-income groups (Tomita et al., 2017). Furthermore, quality of green spaces could also vary by neighbourhood socioeconomic status. Deprived neighbourhoods are less likely to get support for maintaining high quality green spaces, resulting in more safety concerns and less amenity than green spaces in more affluent neighbourhoods (Hoffimann et al., 2017). Our findings support these previous observations from the global South that there may be greater health disparities in green space access and quality in the Colombian context. Given that disparities in quality and safety of green space may also exist, inequitable access to green space by socioeconomic status could present significant challenges in using green space to mitigate health disparities in Cali. The disparities are more likely to increase as urbanization intensifies, further shrinking existing green spaces in poor urban neighbourhoods (Haaland and van den Bosch, 2015).

Another important finding of this study is that the association between neighbourhood greenness and health was partially mediated by physical activity. Although physical activity is widely recognised as one of the most important mechanisms linking green space to health, empirical evidence supporting this hypothesis is rather limited and conflicting. Research conducted in the Netherlands and New Zealand has found that physical activity did not fully explain the relationship between green space and health (Maas et al., 2008; Richardson et al., 2013). On the other hand, a study of Brazilian adults has shown that access to recreational spaces was positively associated with leisure-time physical activity (Parra et al., 2011). Other studies conducted in Colombia also showed that density of public parks was positively associated with physical activity, self-rated health, and quality of life measures (Gomez et al., 2010; Parra et al., 2010; Sarmiento et al., 2010). This difference across studies suggests that availability of green space may not be seen as a necessary condition for physical activity. Especially in high-income countries, supply of other infrastructures, e.g., walking and cycling paths, are relatively high and may be more directly relevant for physical activity. In the absence of these infrastructures, green spaces in low-resource settings may play an important role in increasing opportunities for physical activity and other health-related behaviours.

Although our study offers important insights, there are several limitations. First, our use of cross-sectional data prevented us from making a causal inference on the observed relationships. Our models controlled for socioeconomic factors, but we could not completely rule out the possibility of self-selection bias wherein high-income populations may choose to live in greener areas to further improve their health status. Longitudinal studies would be less prone to such bias by allowing researchers to examine health trajectories over time. Second, our health outcomes came from self-reported measures of health, which could be subject to measurement bias and report bias. However, previous research suggests that subjective health ratings are strongly correlated with objective health data (Idler and Benyamini, 1997; Jylhä, 2009). Self-rated health is a simple but useful measure to identify vulnerable groups in resource-scarce settings (Falk et al., 2017). Our physical activity measure provides useful information about general trends; however, future studies should incorporate more precise measures of physical activity to understand frequency, duration, and intensity. Also, we only examined physical activity as a potential mechanism linking green space to health, but there could be other mediators (Markevych et al., 2017). It should be noted that our mediation models did not account for random intercepts due to convergence issues with the lavaan package in R; therefore, future studies should explore other approaches to reflect the clustered structure of the data. Lastly, we acknowledge that our use of NDVI may not fully capture all forms of natural space or accessibility to public green space (Jarvis et al., 2020; Rugel et al., 2017). It will be useful to explore other green space measures, such as different quality and types of green space to inform future planning decisions in Cali.

5. Conclusions

In this study, we found a significant association between neighbourhood greenness and self-rated health and physical distress in Cali, Colombia. This study also showed that physical activity may be an important underlying mechanism linking green space to health in Cali. However, the beneficial effects of neighbourhood greenness appeared to be much stronger for people living in neighbourhoods with mid- to high-socioeconomic status. This suggests that while a positive relationship exists between green space and health, the more green space does not necessarily mean the better if there is little effort to address socioeconomic health disparities. Furthermore, several decades of research on environmental justice from the global North has demonstrated that urban greening efforts could cause more harm than good if not carefully planned. There is a considerable body of evidence that uncoordinated green space development may actually inflate property values, potentially leading to gentrification and displacement of low-income households (Wolch et al., 2014). As gentrification is a global phenomenon, cities of the global South should pay close attention to not only the existing problems with unequal distribution of green spaces, but also the potential downside of uncoordinated green space development in low-income neighbourhoods.

Findings from this study add to the growing body of evidence showing that urban planning and design have important implications for population health and wellbeing. The cumulative evidence points to the pivotal role that city planning has in improving the quality of life, supporting the "health in all policies" approach. The promotion of people's health is not only the concern of health professionals—urban planning professionals also contribute to population health and wellbeing through a range of interventions in the built environment. City planning and the allocation of public resources through the provision of public goods, such as parks and green spaces, have the potential to improve people's physical health while tackling significant disparities in resource allocation that are rampant in many cities across Latin America. This research calls for the need to further articulate appropriate urban green space strategies that best promote physical activity while explicitly reducing health disparities in order to make informed decisions about future green space development in the global South context more comprehensively.

Acknowledgements

This research was conducted as part of the PEAK Urban Programme, supported by UKRI's Global Challenge Research Fund, Grant Ref.: ES/P011055/1.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2021.102690.

Author contributions

AH: Conceptualization, Methodology, Formal analysis, Writing – original draft preparation, Writing – review & editing; LM: Conceptualization, Data Collection, Writing – original draft preparation, Writing – review & editing; JP: Conceptualization, Data curation, Visualization, Writing – original draft preparation, Writing – review & editing. JD: Writing – review & editing, Funding acquisition; KR: Writing – review & editing, Funding acquisition.

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