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RESEARCH ARTICLE

Leave no one behind: A case of ecosystem service supply equity in Singapore

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Abstract Urban populations benefit greatly from the ecosystem services provided by urban green and blue spaces. While the equity of provision of and access to urban green and blue spaces has been widely explored, research on equity of ecosystem service provision is relatively scant. Using household level data, our study aims to assess the supply equity of five regulatory ecosystem services in Singapore. We employed linear mixed-effects models and Hot Spot Analysis to analyze their distributional equity across individual households of various demographic characteristics (horizontal inequality), and calculated Gini coefficient for the distribution of PM_{10} removal service among households categorised into demographic subgroups (vertical inequality). Our results show little evidence of inequitable ecosystem service provision among Singapore's diverse socio-demographic groups. This can be attributed to the early integration of environmental management strategies and meticulous socio-economic desegregation efforts into urban development plans, which maximised provision and maintenance of urban green spaces to all residents.

Keywords City design and planning · Ecosystem service equity · Environmental justice · Sustainable development · Urban regulatory ecosystem services

INTRODUCTION

Current understanding of urban green and blue spaces and their ecosystem services

Urban green and blue spaces (UGS) and their roles in providing regulatory ecosystem services are vital to the improvement of human well-being (Elmqvist et al. 2015; Brzoska and Spāģe 2020). These ecosystem services in turn contribute to the sustainability and liveability of cities that are projected to be home to more than five billion people globally by 2030 (United Nations et al. 2019). As the urban landscape becomes the predominant type of settlement for the world population (Haase et al. 2014; Tan et al. 2020), the diminishing extent of UGS as a result of urban expansion and densification is becoming a great cause for concern. Global policy frameworks have attempted to secure greater provision of urban ecosystem services in future cities; most notably, the United Nations Sustainable Development Goals (SDG) included SDG11 *Sustainable Cities and Communities* (Make cities and human settlements inclusive, safe, resilient and sustainable), which gives impetus to pursue sustainable urban development inclusively and justly (Capon 2017; United Nations 2017; Scherer et al. 2018). As a consequence, cities face the dual challenge of providing sufficient UGS to enhance climate resilience, as well as uphold environmental justice by providing urban ecosystem services equitably (Haaland and van den Bosch 2015).

Ecosystem services (ESs) are goods and services provided by the natural landscapes that directly benefit human well-being through their natural functions and biophysical characteristics (Haines-Young and Potschin 2017). These benefits support human well-being materially or immaterially, and are broadly categorised into provisioning, regulation and

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maintenance (simplified as "regulatory" hereafter), and cultural services (Haines-Young and Potschin 2017). In an urban landscape, ESs are usually provided for by UGS such as forests, grasslands, managed trees, and waterbodies. Following the recent climate discourses on environmental pressures and their impact on human well-being particularly in cities (Capon 2017; Cox et al. 2018), the ES approach has been slowly but increasingly integrated into urban planning strategies to mitigate urban environmental challenges (Hansen et al. 2015; Cortinovis and Geneletti 2018). For instance, an ES approach to urban heat island (UHI) effect mitigation is most often done through an increase in urban vegetation and canopy coverage (Akbari et al. 2016; Aflaki et al. 2017; Onishi et al. 2010), which contributes to thermal comfort especially in compact cities (Chow and Roth 2006a, b; Wang et al. 2016), therefore reducing heat-related illness. Urban vegetation can also be a cost-effective mitigation tool for air and noise pollution reduction through their air quality regulation and noise absorption abilities (Quah and Boon 2003; De Carvalho and Szlafsztein 2019). Restoration of existing urban drainage networks through vegetation incorporation and increasing perviousness of the urban landscape by adding vegetation are also strategies incorporated into urban flood prevention systems, reducing flood risks and guarding the safety of urban dwellers (Chan et al. 2018; Liao 2019; Lourenço et al. 2020; Miguez et al. n.d.).

The concept of environmental justice and current status in research

Despite the growing recognition of urban regulatory ESs, the resources expended on UGS development and the resulting benefits are usually uneven and environmental injustice often prevails in cities through the disproportionate distribution of air and water pollution (Boyce et al. 2016), and the availability and access to UGS (Fernández-Álvarez 2017; Rigolon et al. 2018; Biernacka and Kronenberg 2019; Geneletti et al. 2020; Wu et al. 2020). This is in part due to the fact that while urban planners operationalise the ES approach in the process of building greener urban landscapes, much of these efforts are dependent on the willingness and financial priorities of the local authorities, and the communities' motivation for environmental stewardship from the ground up (Ernstson 2013; Biernacka and Kronenberg 2018; Andersson et al. 2019; Langemeyer and Connolly 2020).

The concept of environmental justice entails distributional equity, procedural equity, recognitional equity and contextual equity which extends beyond equality, but examines the ethical fairness of resource distribution (Friedman et al. 2018; Kronenberg et al. 2020). Distributional equity is a frequently examined concept of environmental justice, which seeks the just and fair distribution of resources (Tan and Samsudin 2017; Friedman et al. 2018; Nyelele and Kroll 2020). In our study, we focused on the distributional equity of urban ESs and the distribution of opportunity to receive ES benefits provided by UGS in Singapore regardless of the socio-demographic characteristics of locality of residence of an individual. Our study considered individuals who belong to ethnic minorities, live in lower-tier housing and earn lower monthly household income as socially disadvantaged due to their potential lower power of choice or underrepresentation in a society.

Environmental inequity commonly manifests as a result of socio-economical classism or racism (Downey 2005). On the socio-economical dimension, past studies on equity of UGS availability and access have discovered trends of park provisions concentrated in areas dominated by the wealthier, older and more educated population (Heynen 2003; Fernández-Álvarez 2017; Venter et al. 2020; Wu et al. 2020). Economically disadvantaged neighbourhoods also consistently face a disproportionately greater risk of natural hazards and air or water pollution (Fielding and Burningham 2005). On the racial dimension, minority communities such as the Black, Hispanic or Asian population, particularly in the United States, also face higher exposure to environmental pollution (Morello-Frosch 2002; Newell 2005; Bravo et al. 2016; Grineski et al. 2017) and lower quantity and quality of UGS (Heynen et al. 2006; Sister et al. 2010). Marginalised ethnic communities and economically disadvantaged populations often experience greater levels of environmental ills, and fewer opportunities to interact with nature due to geographical limitation or segregation of residential location (Newell 2005; Kelly-Reif and Wing 2016; Cole et al. 2017; Schell et al. 2020). Therefore, these groups often derive a lower level of environmental benefits, and suffer from disproportionately higher exposure to health risks and poorer quality of life (Downey 2005; Heynen et al. 2006).

Urban environmental equity has been widely studied mainly through the aspects of UGS provision and access (Fernández-Álvarez 2017; Venter et al. 2020; Wu et al. 2020). In contrast, equity in the provision of the many ESs provided by UGS has been largely overlooked. One exceptions is a study by Nyelele and Kroll (2020) that found that higher disparities among various demographic groups in the monetary value of carbon-related ESs compared to that of runoff avoidance and $PM_{2.5}$ removal rate in the Bronx, New York City. Riley and Gardiner (2020) also looked explicitly at ESs, demonstrating a negative correlation between social disadvantage and the monetary value of several ESs provided by urban forests in nine U.S. cities. Both studies highlight the importance of contextualising ES equity and its implications on a local scale to better inform urban planning strategies.

In addition, a limited number of existing studies on city-wide urban environmental equity exhibit spatial explicitness through recognising UGS's provision of a variety of ESs at different spatial scales, depending on the landscape composition (Fisher et al. 2009; Beichler et al. 2017; Tan et al. 2020). Existing city-scale assessments often lack the site-specific details of social equity or ecological performance to inform targeted policy solutions for urban well-being and climate resilience improvements (Demuzere et al. 2014; Pandeya et al. 2016). Assessing the equity of urban ES supply at a local, household level is thus the natural next step to the preceding UGS availability and accessibility assessments.

Aims and objectives

While urban environmental equity studies typically reveal disproportionate distribution of environmental resources, in a recent study by Nghiem et al. (2021), evenly distributed UGS availability was observed among Singapore residents. This finding is atypical in comparison to UGS equity assessments in other countries, and underscored the role that historical urban planning has played in aiding the preservation of UGS equity. Given the potential of urban UGS in providing urban ESs beneficial to human well-being, our study aims to build on Singapore's case of UGS equity to contribute to the still nascent state of distributional ES equity studies using Singapore as a case study. While we acknowledge that procedural, recognitional and contextual equity also contribute to environmental equity, discussions in these aspects are beyond the scope of the present study as these forms of equity exhibit ambiguity when analysed spatially. Therefore, our study aims to first establish the status of environmental equity in Singapore as it has not been systematically studied on the subject of ecosystem services.

By assessing the distribution of five regulatory ESs in Singapore at the household level, this paper aims to investigate if the respective supply of particulate matter (PM_{10}) removal rate, runoff retention rate, soil erosion reduction potential, temperature reduction due to presence of vegetation (hereafter "temperature change") and noise abatement services provided for by UGS are.

1. equitably distributed relative to the spatial distribution of Singapore residents
2. equitably distributed among Singapore residents of various demographic characteristics.

With the conscious shift towards a more sustainable and equitable development driven by SDG11, the case of Singapore can provide insights into the effective environmental management for urban tropical cities and inform relevant urban planning strategies to ensure environmental sustainability, social inclusiveness and equity in the development of a multi-cultural society.

MATERIALS AND METHODS

Singapore as an urban case study

With a population density of 7810 people per km^2 (Department of Statistics 2020), Singapore is the second densest country in Southeast Asia (The World Bank, n.d.), housing a pluralistic urban society of varied socio-economic status and demographic characteristics. Singapore is a city state which has urbanised in a short span of 50 years, growing from a nation dominated by rural settlements to a developed nation of 100% urban population (United Nations et al. 2019). Singapore has a substantial home ownership rate of 90.4%, where 95% of home owners reside in public housing flats (HDB flats) developed by the Housing and Development Board (HDB) or private condominiums, and only 5% of home owners live in landed properties (Department of Statistics 2021). The composition of dwelling type indicates that only a small portion of Singapore residents residing in landed properties have the ability to increase UGS around their houses to improve the supply of regulatory ESs, but the remaining majority rely more heavily on the private developers or government-led developments to improve and maintain the surrounding landscapes (Nghiem et al. 2021). While the rapid development has replaced the majority of Singapore's original forest cover with urban infrastructure, the issue of the diminishing natural landscape was recognised since the 1960s. The 1967 *Garden City* initiative subsequently marked the beginning of Singapore's commitment towards an environmentally conscious development (Tan et al. 2013). The initiative has since evolved into the *City in a Garden* strategy in 2003 and most recently the *City in Nature* vision in 2020 (Carrière et al. 2020).

Environmental management strategies have been integrated into Singapore's extensive urban planning efforts as the nation aims to be among the greenest and most liveable cities in the world (Leitmann 1999; Tan et al. 2013). Ongoing environmental management strategies include the restoration of the environment and natural functions of the water bodies (Han 2017; Liao 2019). Singapore is also focusing its environmental management strategies on improving the availability, accessibility and connectivity of the green and blue spaces across the island (Yeo 2019). Efforts in construction of neighbourhood parks, planting of street trees and extension of park connector networks built up a city of close to 50% green cover (Tan 2006; Han 2017), achieving a landscape allowing more than 80% of households living within 10-min walk of a park (Ministry of the Environment and Water Resources 2016).

Singapore has devoted substantial efforts into urban and environmental management. However, the city could still be susceptible to urban environmental injustice due to the highly pluralistic demographics in terms of socioeconomic status and ethnicity (Lim et al. 2019). Racially, the Singapore population is dominated by Chinese (75.9%), a sizeable minority of Malays (15.1%) and Indians (7.4%), and other ethnicities including Caucasian, Eurasian and other (1.6%) (Prime Minister's Office et al. 2021). Socioeconomically, Singapore's income distribution is moderately unequal with a Gini coefficient of about 0.402, and an average monthly household per capital income ratio of 23.8 between the top versus bottom 10% population as of 2018 (Peng 2019). A relatively equitable distribution of regulatory ESs could therefore ensure that regardless of sociodemographic background, no particular community will be unfairly disadvantaged or privileged in the provision of ESs that support the maintenance of urban human wellbeing.

Mapping ecosystem service provision

We focused on five distinct regulatory ESs including PM_{10} removal rate, runoff retention rate, soil erosion reduction potential, temperature change and noise abatement. The supply of these ESs at a national level were modelled using various spatial characteristics and climate scenarios using the R programming language (details on the specific mapping of ESs are provided in the Supplementary Information). The ES models used in this study have been published open-source, as part of the NCS2020 package for the R statistical computing language (Richards et al. 2021). An outline of the conceptualisation of the ES models is described in the following sections. Further details on the procedures are provided in Appendix Table S9 and the R package documentation (Richards et al. 2021).

PM_{10} removal rate

The air quality regulation service is expressed as the amount of PM_{10}, sized between 2.5 and 10 µm, removed by vegetation per m^2 of an area per day. In Singapore, PM_{10} is a major air pollutant, mainly contributed by industrial and vehicular emissions, and periodic transboundary haze (Li and Tartarini 2020; Zhu et al. 2020; National Environment Agency 2021). Although other air pollutants such as NO_2 and SO_2 from road traffic could also be accounted for in air quality approximation, they are comparatively lower in concentration and have less pronounced health implications (Yap et al. 2019; Zhu et al. 2020). PM_{10} removal was modelled under the conditions of no precipitation and relatively high ambient PM_{10}. The final model was developed and adapted from established ES modelling studies performed in the urban context (Zinke 1967; Gryning and Chaumerliac 1998; Escobedo and Nowak 2009; Manes et al. 2014; Bottalico et al. 2016)

To calculate the total PM_{10} removed over a period of one day, data on PM_{10} deposition flux and resuspension rate, PM_{10} concentration and leaf area index (LAI) were collected. Standard values for the PM_{10} deposition flux and resuspension rate were used following that established in previous urban ES modelling studies under similar urban parameters. The annual 99th percentile daily (24 h) average PM_{10} concentration of 84 µg per m^3 was used as the constant value for PM_{10} concentration throughout Singapore (National Environment Agency 2020). This average value was observed over the period between 1994 and 2014; this represents a relatively high exposure to PM_{10} in Singapore. As the model used was multiplicative in nature, PM_{10} removal rate would scale linearly with changes in the reference concentration. Thus, the choice of reference concentration would not influence relative spatial variation in the estimation. The leaf area index was parameterised for all land areas covered by trees. For tree canopy above 2 m in height, the LAI was taken from a national LAI map developed using remote sensing (Richards and Wang 2020a, b). The LAI for vegetation cover with canopy height below 2 m was modelled using a coarse national map of vegetation height under the assumption that leaf density is evenly distributed throughout the tree canopy (Dissegna et al. 2019). For other vegetation cover without tree canopy, a minimum LAI of 2 was assigned following the URA LUSH programme guidelines (Urban Redevelopment Agency 2014).

Runoff retention rate

The runoff retention rate represents rainfall runoff prevented by an ecosystem, denoted using curve number (USDA 1986). This was modelled using a "large storm" precipitation condition in Singapore (> 70 mm/h) to better represent the extent of runoff retention service provided by our urban ecosystem (Chow et al. 2016). We assumed that the precipitation condition was uniform over Singapore. With increasing frequency of high intensity precipitation events in Singapore, the annual maximum hourly rainfall recorded reached 110 mm/h in 2010. This value was therefore used as an input in our model to simulate the extent of an extreme rainfall event.

Subsequently, we used the USDA guidelines (USDA 1986) which provide the curve number assigned to 13 different classes of land use and four soil types (Table S1). All urban soils were assumed to have low quality soil (soil D) and all forests soils were assumed to have high quality soil (soil A).

Soil erosion reduction potential

The soil erosion reduction potential is expressed as the difference between the total actual soil loss and the potential soil loss assuming an absence of vegetation. We followed the method proposed by Guerra et al. (2014) for modelling soil erosion reduction potential using an adapted version of the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). The actual soil loss was estimated using USLE with data on rainfall runoff factor, topographic factor, soil erodibility factor and vegetation cover factor. The potential soil loss was modelled using the same method except in the absence of vegetation cover factor.

The rainfall runoff factor was obtained from a global dataset on erosivity (Panagos et al. 2017). The topographic factor was measured as the soil erosion tendency of the landform, calculated from the digital elevation model designed to facilitate USLE integration (Moore and Burch 1986). The soil erodibility factor was modelled using clay content and size distribution of soil particle for five common vegetation types from available field samples as previously proposed by the USLE (Renard et al. 1997; Fung et al. 2021). For ecosystem covers without available soil data, the soil erodibility factor value of the most similar ecosystem type was applied. The vegetation cover factor was obtained from satellite imagery, converted using the normalised difference vegetation index (NDVI) following the method of the European Commission European Soil Risk Assessment (Van der Knijff et al. 2000).

The final value was calculated for each terrestrial pixel on mainland Singapore by calculating the difference between absolute soil loss and potential soil loss.

Temperature change

Temperature change is expressed as the effect of urban landcover composition on the extent of ambient air temperature change, measured in degree Celsius. Air temperature data were collected from two weather station networks in Singapore, covering 45 weather stations across Singapore. Our analysis took data between 1st October 2015 and 2nd October 2018, aggregated into hourly mean values for each weather station by taking the mean of all measurements within the hour. The final model subsequently modelled the change of ambient temperature as a function of the area of various land cover types within radial buffers of various spatial scales around each weather station. The land cover types include unmanaged vegetation, managed tree cover, managed grass and shrub cover and surface water, estimated using a map detailing the terrestrial ecosystem of Singapore (Gaw et al. 2019).

Noise abatement

Noise abatement is represented as the total noise attenuated from the source of noise due to the presence of vegetation absorbing and scattering the sound waves, after accounting for other types of attenuation including spherical spreading loss, atmospheric absorption loss, topographic and barrier effect. This was performed using a modified model originally developed by the System for the Prediction of Acoustic Detectability (SPreAD) model, which is a 2-dimensional mechanistic model developed for conservation and ecological planning (Reed et al. 2012). The general conceptualisation of the noise attenuation estimation approach utilised for this analysis was originally proposed as part of the International Organisation for Standardisation guideline on attenuation of sound during propagation outdoors (ISO 9613-2 1996). The modelling of various types of noise attenuation were done following globally established methods from the Acoustic Society of America (ANSI S1.26 1995), the US Environmental Protection Agency (R. T. Harrison et al. 1980a, b), and the SPreAD-GIS model (Reed et al. 2012).

For the estimation of noise attenuation in Singapore, the typical daytime atmospheric conditions of 30 °C and 70% humidity were parameterised (Chow and Roth 2006a, b). A random sample of 30,000 points, representing hypothetical locations of vehicles emitting noise, were taken along the road network of Singapore to be used as point sources of noise, generating noise of 70 dB, an intermediate to high level of traffic noise (Ma and Yano 2004; Chin et al. 2019a, b). Due to the constraint that noise attenuation value cannot be negative, any result with negative values were moderated and replaced with 0. The model then generated a continuous national map of the capacity of vegetation to attenuate road traffic noise.

Assessing inequality

The correlation between household socio-demographic characteristics and the provision of ESs were studied through horizontal and vertical inequality assessment and spatial analyses using the R programming language (R Core Team 2020) and ArcGIS Pro.

An online national survey was conducted by a market research company (IPSOS) on 1500 Singapore residents (Singapore citizen or permanent resident) in May 2019 (Appendix S1). Our survey was approved by the National University of Singapore Institutional Review Board (reference code: S-19-094E). To ensure that our sample was nationally representative, the survey sampling was conducted with quotas set according to the sociodemographic composition of the Singapore population (e.g., gender, ethnicity and age). The data collected personal and household data including age, gender, ethnicity, religion, citizenship status, occupation, education level, number of family members, number of children in the family, monthly household income, and type of housing. After removing incomplete responses, 1395 were sufficiently complete for our analysis.

The respondents were asked to provide the location of their households in the form of postal codes. In Singapore, a postal code is a unique identifier of residential location on a building-level. For the respondents living in public housing and condominiums, full six-digit postal codes were provided. On the other hand, due to privacy considerations for the 72 respondents residing in landed properties where full postal codes would reveal the precise residential location, only four out of six digits were provided. Therefore, for landed properties, random generation of a residential postal code was done using the residential district of the respondents. As landed properties are generally located in clusters within each residential district, the process of random selection is not expected to substantially compromise on the accuracy of the household's surrounding landscape composition for subsequent analyses.

To quantify ES supply for individual households, the household locations (Fig. 1) were each used as a centroid for the generation of three buffers of radii 500 m, 1000 m and 1500 m. The extent of each buffer was then overlaid onto the maps of ES supply (Appendix S7) for the calculation of area-based mean ES supply for each respondent household. The variation in spatial scales with the use of three buffer sizes aimed to take into account the potential landscape heterogeneity which could influence the availability of ES-providing UGS to households at various distances. These distances correspond to Singapore's national UGS provision target (500 m and 1000 m) (Tan and Samsudin 2017) and the standard walking distances around a household within which physical or recreational activities are likely to take place (500 m, 1000 m, 1500 m) (Kaczynski et al. 2014; Schipperijn et al. 2017). As the availability of parks in Singapore was found to be correlated to scale (Tan and Samsudin 2017), we believe that the heterogeneous land cover composition could have implications on the provision of ESs as well (Hu et al. 2015; Dronova 2017). Therefore, the variation in buffer sizes could potentially provide a spatial perspective to the equity of ES distribution.

Subsequently, ES distribution will be assessed based on horizontal and vertical inequality measures elaborated below. The horizontal inequality measure assesses distributional equity among subdivisions of a population in terms of demographic characteristics (Boyce et al. 2016), while the vertical inequality measure assesses distributional equity aggregated across specified demographic variables (Nghiem et al. 2021). These are approaches developed for a more precise understanding of the distributional patterns of environmental variables (Boyce et al. 2014, 2016; Nyelele and Kroll 2020). The horizontal and vertical inequality measures were therefore chosen as they allow a straightforward comparison of ES distribution among population subgroups of interest (Nghiem et al. 2021).

Horizontal inequality with information theoretic approach

The measure of horizontal inequality assesses the distribution of ESs for Singapore residents belonging to different demographic groups.

We adopted an information theoretic approach (Blankenshipa et al. 2002) where linear mixed effect models were proposed to assess the correlation between 11 socio-demographic explanatory variables, in various combinations, and the distribution of supply of ESs (response variables) (Appendix S2). Multicollinearity was assessed through examining the pair-wise correlation plots between each pair of the explanatory variables and the variance inflation factor (VIF) using the vif function in R. None of the explanatory variables were found to be collinear (VIF scores < 3).

In total, 15 sets of models were run for the distribution of each of the five ESs at three spatial scales (500 m, 1000 m, 1500 m buffer zones). In each set, seventy models (Appendix S3) were proposed based on themes gathered from past literature and relevant contextual knowledge about the distribution of ESs (Blankenshipa et al. 2002). They took on the following form:

$$Y = \beta X + \mu Z + \varepsilon,$$

where Y is the response variable representing the mean ES supply at 500 m, 1000 m, 1500 m buffer zones of each household, β is a vector of regression coefficient for the fixed effects, X is the vector of the fixed effects, μ is the coefficient of the random intercept, Z is the random effect and ε is the error term. Z and ε were assumed to be normally distributed. For the distribution of PM_{10} removal rate, temperature change, runoff retention rate and noise abatement, Y was subjected to log transformation to achieve a closer conformation to the normal distribution.

A random intercept of 37 planning areas (out of a total of 55), the geographical subdivision of urban planning census in Singapore (Chew 2009) (Appendix S6), was included in the model to account for spatial autocorrelation and the potential variation in the extent of environmental management among planning areas. This corresponds to the 37 planning areas where the respondents reside in.

Within each set of analysis, models were ranked according to the smallest Akaike information criterion (AIC) value. Subsequently, the best models with cumulative Akaike weights of at least 0.95 were selected for full-

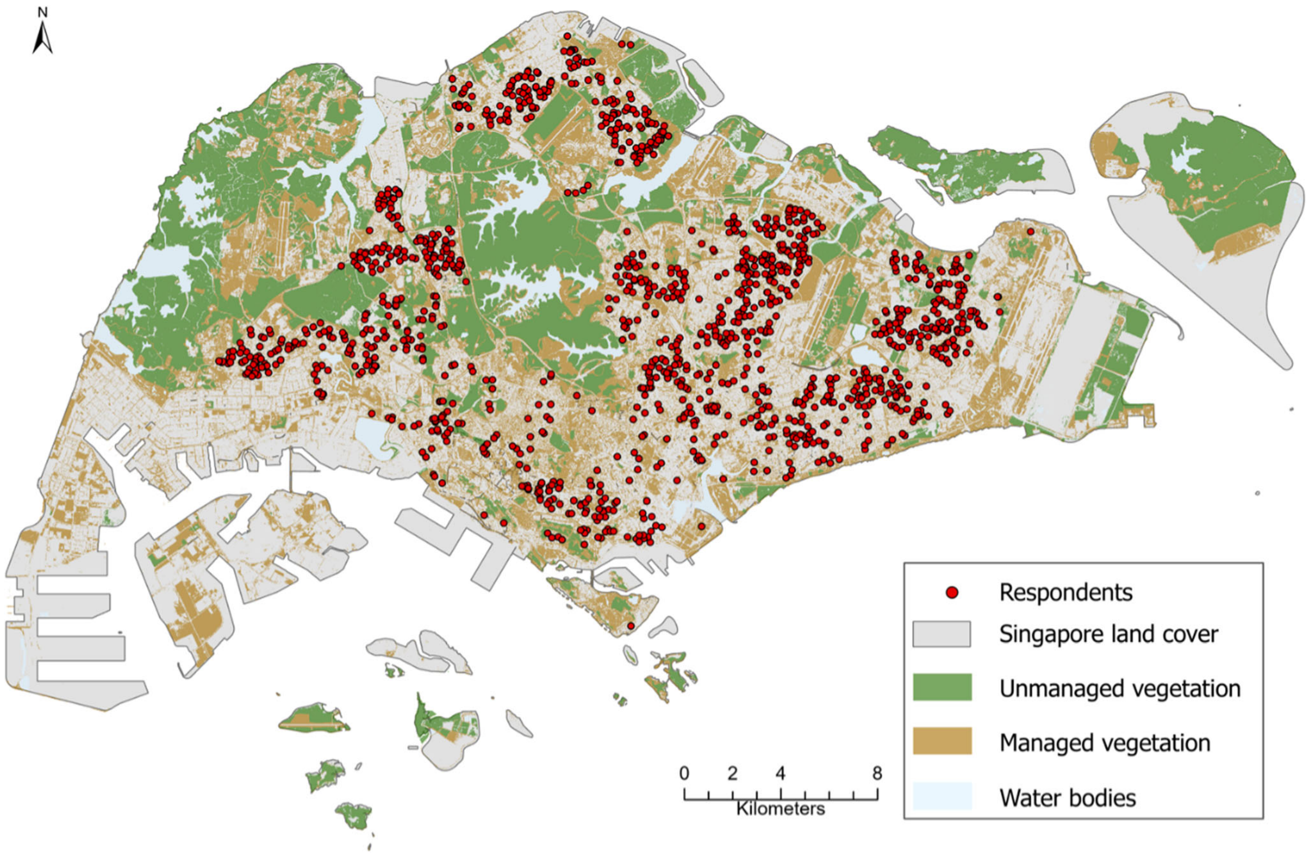

Fig. 1 Residential location of the 1395 respondents

model averaging, where the final model was obtained (Symonds and Moussalli 2011; Galipaud et al. 2014).

To validate the outcome of the above models, the Hot Spot Analysis (Getis-Ord Gi∗) tool on ArcGIS Pro (Esri, n.d.) (Appendix S5) was used to identify local spatial clusters for household income, type of housing and ethnicity. These characteristics were visualised and assessed due to their potential to drive the formation of social enclaves, which could cause disproportionate distribution of ES.

Vertical inequality with Gini coefficient

The measure of vertical inequality uses the Gini coefficient to assess the distribution of ESs for Singapore residents aggregated into demographic subgroups based on specified demographic characteristics such as income levels and residential neighbourhood (Boyce et al. 2016). Gini coefficient is a well-established indicator of resource distribution equality first developed for the distribution of wealth (Kim and Jargowsky 2009). It has been adopted by environmental researchers mainly to quantify equity in exposure to pollution, hazard risk and the availability of nature-related infrastructure (Millimet and Slottje 2002; Sun et al. 2010; Li et al. 2016; Rój 2020). The environmental application of the Gini coefficient, termed environmental Gini coefficient (G), takes the form:

$$G = 1 - \sum_{i=1}^{n} \left(X_i - X_{(i-1)}\right)\left(Y_i - Y_{(i-1)}\right),$$

X is the cumulative percentage of the population, often divided into i subgroups based on a particular characteristic, and Y is the cumulative percentage of ES supply for each of the i subgroups, and G is the environmental Gini coefficient which indicates the level of inequality. The absolute value of Gini coefficient ranges from 0 to 1 where 0 represents perfect equality and 1 represents perfect inequality. To interpret the Gini coefficients, we adopt the categorisation proposed by Zheng et al. (2013) which has been used for studies examining land property and ES distributions (Benra and Nahuelhual 2019) where an absolute value of Gini coefficient of less than 0.2 indicates "absolutely equal"; 0.2 to 0.3 indicates "relatively equal"; 0.3 to 0.4 indicates "reasonably equal"; 0.4 to 0.5 indicates "relatively unequal"; and greater than 0.5 indicates "absolutely unequal".

In this study, nine Gini coefficients were calculated for the distribution of PM_{10} removed per m^2 per day at three spatial scales (500 m, 1000 m, 1500 m) aggregated based on household monthly income level, housing types and ethnicity. There are 21 levels of household monthly income (ranging from \$1000 and below to \$21 000 and above, banded by an increment of \$1,000), seven housing types (2-room flats, 3-room flats, 4-room flats, 5-room flats, executive condominium, private condominium and landed properties) arranged in increasing level of pricing premium, and four ethnicity categories (Chinese, Malay, Indian, Others).

The same measure of vertical inequality is unable to be assessed for four other ESs as their units of measure come in the forms of percentages, degree Celsius and decibels, which do not make ecological sense when summed across the population.

RESULTS

Distribution of regulatory ecosystem service provision

The supply of regulatory ESs varies across the terrestrial extent of Singapore (Appendix S7). Across the entire study region, the supply of PM_{10} removal rate ranges between 0 and 35.8×10^{-3} mg/m^2 per day, temperature change ranges between 0 and − 4.7 °C, runoff retention potential ranges between 5.5 and 97.4%, soil erosion reduction potential ranges between 0 and 99.9% and noise abatement ranges between 0 and 14 dB. In general, all ESs were observed to have higher level of supply in the Central and Western regions. This could be attributed to the presence of unmanaged vegetation that generally has a greater capacity to supply ESs due to its structural and functional complexity (Krug et al. 2012).

The supply of regulatory ESs varied slightly across our 1395-respondent sample (Fig. 2). Modest increases are observed for the mean levels of ES supply across the three buffer sizes (500 m, 1000 m, 1500 m): 2.5×10^{-3}, 2.8×10^{-3} and 3.1×10^{-3} mg/m^2 per day, respectively, for PM_{10} removal rate, − 1.1, − 1.2 and − 1.3 °C, respectively, for temperature change, 23.4%, 27.1% and 30.0%, respectively, for runoff retention rate, 57.1%, 60.9% and 63.4%, respectively, for soil erosion reduction potential and 2.1, 2.7 and 3.0 dB, respectively, for noise abatement (Table 1).

Horizontal inequality in the distribution of regulatory ecosystem service provision

The results of the model averaging show that in all the 15 sets of models for all the three buffer sizes (500 m, 1000 m, 1500 m) and five regulatory ESs (PM_{10} removal rate, temperature reduction, runoff retention rate, and soil erosion reduction), four variables were consistently present in the top models (Fig. 3), contributing to the averaged model in varying weightages (Appendix S4). These were gender, number of family members, number of children, and citizenship status. These results suggested that these variables were useful predictors of the distribution of such services in Singapore, while the other variables (monthly household income, age, ethnicity, religion, occupation, highest education level and type of housing) were not important. Among the four consistent predictors, citizenship status was relatively the most important predictor by weight, followed by gender, number of children and number of family members (Appendix S4). However, none of these variables were statistically significant in the averaged models, we thus have insufficient evidence to suggest that the socio-demographic characteristics included in this study affect the distribution of ESs in Singapore.

The Hot Spot Analysis (Getis-Ord Gi ∗) tool was used to statistically confirm the absence of spatial clustering which validates the horizontal equality of ES supply. The distributions of household monthly income (Fig. 4a) and ethnicity (Fig. 4b) did not show any local clustering. However, some premium housing types are observed in greater quantity in the Eastern side of Singapore (Fig. 4c). While based on the outcome of the hotspot analysis, local clusters of respondents living in premium housing can be observed (Fig. 4d), these hot spots consist of several housing types including 4-room HDB flats, Executive condominium, private condominiums, and landed properties. Therefore, the provision of ESs is unlikely to be disproportionately distributed to respondents of any specific housing type. This reinforces the result from the horizontal inequality analysis that no specific socio-demographic group is disproportionately disadvantaged or privileged in the distribution of urban regulatory ES supply.

Vertical inequality in the distribution of PM_{10} removal rate

The Gini coefficients for the distribution of PM_{10} removal rate aggregated by household monthly income level were approximately 0.00316, 0.000247 and -0.00604, that aggregated by housing type were approximately 0.00673, 0.00401 and − 0.00128, and that aggregated by ethnicity were approximately − 0.00627, − 0.000542 and − 0.000330 at 500 m, 1000 m, 1500 m buffers, respectively (Appendix S8). The positive Gini coefficients suggest that at 500 m and 1000 m buffer sizes, households of lower income levels and housing types of lower premium receives slightly lower supply of PM_{10} removal service, and the negative Gini coefficients for 1500 m buffer suggest the reverse. In the case of ethnicity, the negative Gini coefficients suggest that the Chinese respondents receives slightly higher supply of

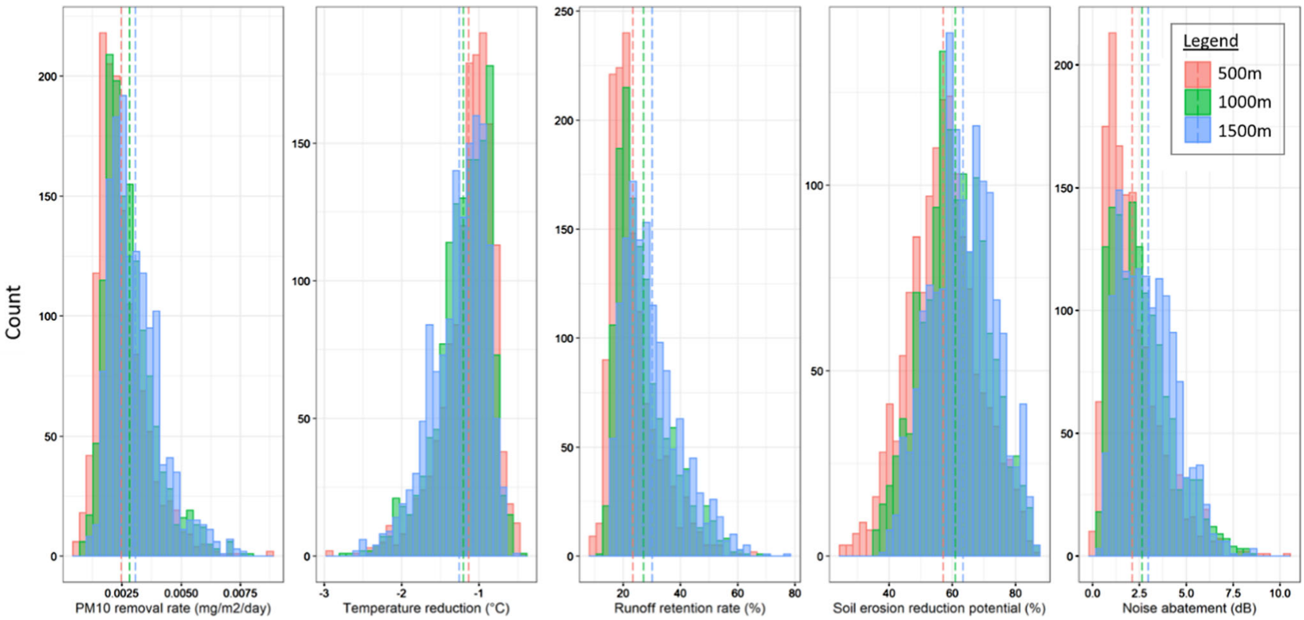

Fig. 2 Level of regulatory ESs **a** PM_{10} removal rate, **b** temperature change, **c** runoff retention rate, **d** soil erosion reduction potential, **e** noise abatement within buffer sizes 500 m, 1000 m, 1500 m around respondents' residence. The mean levels of regulatory ESs supply are indicated by the dashed lines

Table 1 Minimum (Min), maximum (Max) and mean levels of five regulatory ES supply at three buffer sizes (500 m, 1000, 1500 m)

Regulatory ES	Supply of regulatory ES								
	500 m			1000 m			1500 m		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
PM_{10} removal rate ($\mathrm{mg/m^2}$ per day)	0.5×10^{-3}	8.7×10^{-3}	2.5×10^{-3}	0.8×10^{-3}	8.0×10^{-3}	2.8×10^{-3}	1.0×10^{-3}	7.6×10^{-3}	3.1×10^{-3}
Temperature change (°C)	− 0.5	− 3.0	− 1.1	− 0.4	− 2.8	− 1.2	− 0.5	− 2.6	− 1.3
Runoff retention rate (%)	9.4	66.4	23.4	12.0	70.2	27.1	15.5	77.2	30.0
Soil erosion reduction potential (%)	25.4	86.7	57.1	35.7	86.4	60.9	39.1	86.0	63.4
Noise abatement (dB)	0.1	10.5	2.1	0.2	8.5	2.7	0.5	8.7	3.0

PM_{10} removal service compared to respondents of Malay, Indian and Other ethnicities. Nonetheless, across the entire sample, all nine Gini coefficient values indicate close to perfect equality in ES supply distribution (Zheng et al. 2013; Benra and Nahuelhual 2019) (see "Methods" section).

The Lorenz curves were also plotted for the distribution of PM_{10} removal rate by income levels, housing types and ethnicity (Appendix S8). With increasing scale, the Lorenz curves show decreasing deviation from the line of perfect equality. This supports the Gini coefficients in showing only a slight inequality in the distribution of PM_{10} removal service supply.

DISCUSSION

Through horizontal and vertical inequality analyses, our study revealed that there is little evidence of inequity in the current distribution of urban regulatory ESs in Singapore. Our findings show an absence of statistically significant correlation between the various socio-demographic groups and the supply of ESs despite a spatially variable ES supply levels across Singapore. In addition, the low magnitude of Gini coefficient values indicates close to perfect equality in ES supply distribution among respondents with varying income levels, housing types and ethnicities. Based on

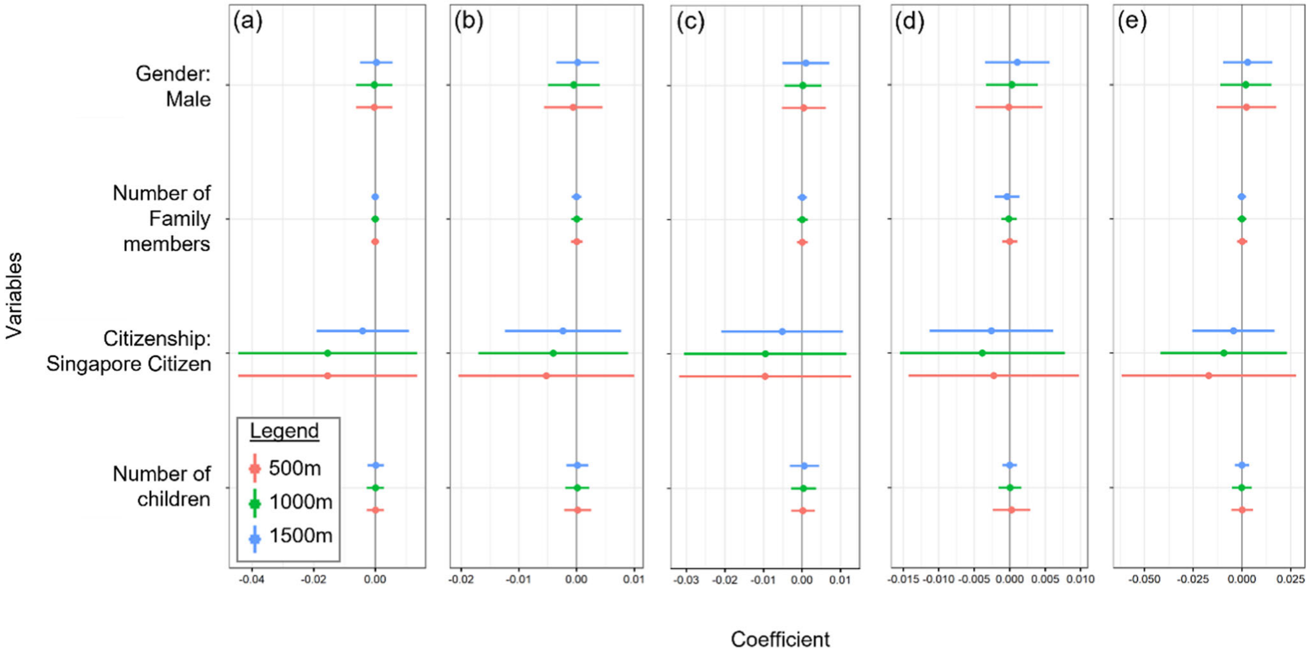

Fig. 3 Result of model averaging derived from full averaging of best models (cumulative weight of at least 0.95) for all 15 analyses of three buffer sizes (500 m, 1000 m, 1500 m) on five regulatory ESs: **a** PM_{10} removal rate, **b** temperature change, **c** runoff retention rate, **d** soil erosion reduction potential and **e** noise abatement. *Y*-axis shows the dependent variables in the final averaged models and *X*-axis shows the respective effect sizes with 95% CI. The baseline for the categorical variables Gender and Citizenship are Female and Permanent Resident, respectively

these results, our study postulates that the case of environmental equity in Singapore could be a result of decades of meticulous urban planning; firstly, through the nationwide greening policies that aimed to holistically improve Singapore's urban landscape (Han 2017), and secondly, through social integration policies that limits the formation of socio-spatial segregation in residential spaces (Lim et al. 2019). These national-scale social and environmental management policies could potentially prevent ES supply inequity (Nghiem et al. 2021). Environmental equity can therefore be upheld in cities when both social and environmental management are adequately incorporated into the process of urban development.

Environmental equity in Singapore

Despite the heterogeneity in the socio-demographic structure of Singapore and the spatial variability in ES supply across Singapore's landscape, our study showed a relatively equitable distribution of urban regulatory ES among the residents. This makes the case of environmental equity in Singapore particularly unexpected in contrast with the results of prior studies in other cities (Rigolon et al. 2018; Nyelele and Kroll 2020; Riley and Gardiner 2020). In most cases of environmental inequity, systematic racism and classism has driven the geographical segregation of the socio-economically disadvantaged and privileged communities, resulting in clustering of socio-economic and socio-demographic communities (Nyelele and Kroll 2020; Venter et al. 2020; Wu et al. 2020). This socio-geographical polarization of neighbourhoods often leads to differential abilities to afford housing in greener neighbourhoods, financial means to pay for private landscaping resources and varied priorities for environmental investments given by private developers or the governments (Heynen et al. 2006; Pham et al. 2012; Wu et al. 2020). In contrast, Singapore's UGS management framework from a national to a household level are less dependent on private interests and financial capabilities.

Singapore's brand of centralised environmental governance sets itself apart from past case studies in which the urban natural landscape has been shaped heavily by the political and economic plans of the government as opposed to private motivations and bottom-up decisions (Han 2017). This can be observed in the recent environmental development initiatives that have placed great emphasis on improving Singapore residents' well-being inclusively, thus contributing towards the provision of UGS and the corresponding ESs in a non-differential approach. For instance, *Sustainable Singapore Blueprint 2015* endeavoured to improve UGS availability and accessibility throughout Singapore, through specific aims to achieve 0.8 ha of public park provision for every 1 000 people and ensure that 90% of households are within a 10-min walk of a park (Ministry of the Environment and Water Resources 2016). The latter target was further

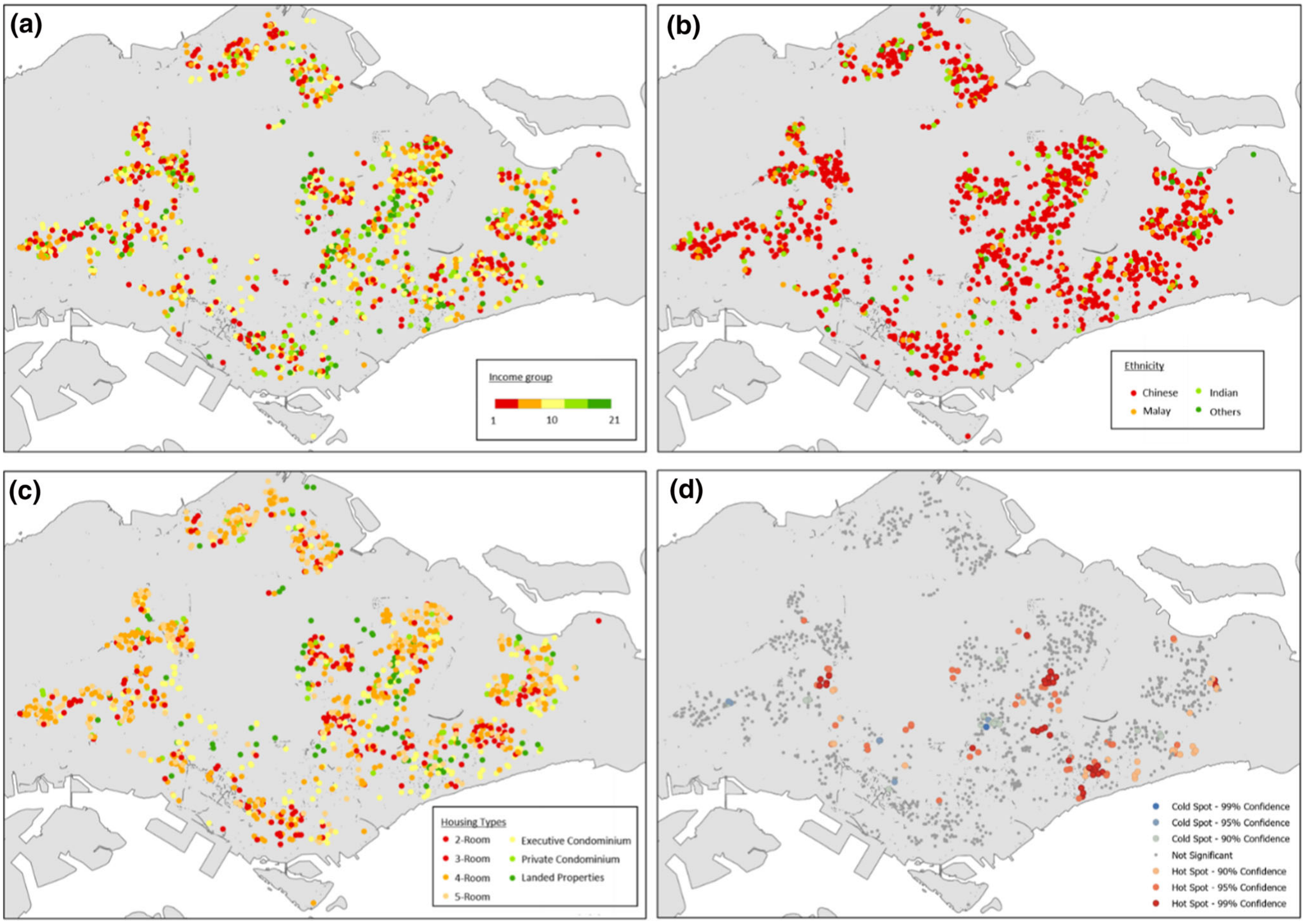

Fig. 4 Distribution of 1395 respondents by **a** 21 income groups, **b** 7 housing types (excluding housing type “others”), **c** 4 ethnicity groups and **d** Result of Hot Spot Analysis (Getis-Ord Gi*) showing the distribution of housing type hot and cold spots

enhanced to reach 100% of households in *Singapore Green Plan 2030* (Singapore Green Plan 2021). These centralised environmental initiatives sought to shape the urban environment holistically (Han 2017; Yeo 2019); they therefore do not rely on the residents’ ability or private developers’ interests to improve neighbourhood landscapes, nor were they differentially implemented based on socio-demographic characteristics of the neighbourhoods. This suggests that centralised environmental management can potentially regulate existing geographical imbalances in private motivation to improve neighbourhood landscapes, thus play a role in preventing environmental inequity.

Role of social policies

The absence of statistically significant correlation between the various socio-demographic groups and the supply of ESs, coupled with the result of the hot spot analysis, verified the absence of ethnic and housing spatial clusters among our study respondents. These results suggest that the equitable distribution of urban regulatory ESs in Singapore could be attributed to its unique urban planning paradigm which has been purposeful in maintaining social desegregation (Seik 1996; Yuen 1996; Han 2017). These social management strategies potentially brought about spill-over impacts beyond their intended aim of maintaining social cohesion, and indirectly contributed towards the prevention of environmental inequity in Singapore. Singapore’s ethnically and socio-economically diverse demographic could potentially be drivers of environmental inequality due to its historical geographical segregation of ethnic communities (Lim et al. 2019). Yet, housing distribution management and ethnic integration policies worked in concert to limit the formation of ethnic residential enclaves (Phang and Helble 2016; Lim et al. 2019). Most prominently, the Ethnic Integration Policy introduced in 1989 de-clustered all ethnic residential enclaves and homogenised the residential composition in terms of ethnicity throughout Singapore’s public housing landscape (Phang and Helble 2016; Lim et al. 2019). Desegregation of socio-economic classes is further enforced by building a mixture of housing types of various premium levels in the same neighbourhood (Teo 2019). This substantially integrated households from different socio-economic classes spatially. This concept was concretised in 2018 in a parliamentary debate that rental flats (lowest tier housing units) will be integrated with the sold flats (housing units of higher premium levels) to promote social integration and alleviate pressures of inequality (Wong 2018). These urban planning strategies, although not designed to prevent environmental inequity, play significant roles in reducing geographical detachment of the most disadvantaged socio-economic groups.

The role of social policies in preventing environmental inequity in Singapore therefore demonstrated the socio-ecological interaction of a city where the urban environment is shaped by human agency and the processes of social and natural resource management exercised through social and environmental policies (Schell et al. 2020). By maintaining a socio-demographically integrated residential composition, neighbourhood greening efforts could more equitably serve a mixture of socio-demographically diverse residents, enhancing ecosystem service provision without disproportionately disadvantaging or favouring a particular community.

The state of environmental equity in Singapore serves as a precedent for its tropical counterparts, exemplifying the managerial rigor required in order to prevent environmental inequity. The environmental challenges faced by Singapore mirrors that of other tropical cities that are similarly undergoing rapid urbanisation and economic development. For instance, cities in both Malaysia and Indonesia have been experiencing intensifying UHI and air pollution (Rushayati et al. 2016; Aghamohammadi et al. 2020). These countries have also been looking towards an ES approach for the development of environmental solutions (Aflaki et al. 2017; Setiowati et al. 2018). However, meticulous land use planning and social integration such as that observed in the case of Singapore is required for social and environmental planning policies to work in concert and prevent environmental inequity. This strategy adopted by the Singapore government therefore necessitates meticulous adaptations and contextualisation for potential application in other tropical urbanising cities.

Spatial variability of regulatory ES supply remains a concern

Based on our 1395-respondent sample, substantial differences in ES supply occur at various buffer scales nonetheless. For instance, at 500 m buffer, the air temperature changes due to urban ES ranges between 0.5 to 3 °C reductions; the level of noise abatement service ranges between 0.1 and 10.5 dB. The geographical disparities in ES supply received by households across Singapore could be a result of an uneven distribution of managed and unmanaged vegetation. This suggests that spatial variability in ES supply remains a cause for concern in the pursuit of inclusive sustainable development. While numerous urban development plans have been designed to increase the area of UGS in cities, it is crucial to recognise that efficient ES provision depends not just on the areal coverage of UGS but also the composition of urban landscapes and the ES needs of the urban inhabitants (Graça et al. 2018; Grêt-Regamey et al. 2020). This is particularly pertinent for densifying cities with an increasing demand for ES as space constraints often pose as a challenge for efficient UGS planning and incorporation (Grêt-Regamey et al. 2020). Over five decades of development in Singapore, a low 0.28% of natural, unmanaged vegetation remained (Tan et al. 2013); mainly in the central and western catchment areas with high levels of urban regulatory ES supply. These are protected areas gazetted for the purpose of enhancing water security in Singapore (Tortajada 2006). To restore environmental sustainability in the city's development, UGS was extensively introduced into the cityscape through various greening policies since the 1960s ("Singapore as an urban case study" section). As a result, Singapore has 50% vegetation cover, dominated by managed vegetation (Tan et al. 2013; Gaw et al. 2019). However, these constructed green landscapes are comparably less effective in providing urban regulatory ESs.

Therefore, a quantitative increase in UGS coverage is not a panacea for enhancing urban ES provision, and the functionality of UGS should be maximised by incorporating the appropriate natural landscape compositions (Grêt-Regamey et al. 2020). As mentioned above, ES supplies concentrate in the protected catchments in Singapore which are rarely in close proximity to residences. The residential areas, dominated by constructed and managed vegetation, is observed to receive substantially lower urban regulatory ESs. In this context, urban ES supply in the ES-deficient regions in Singapore could be improved by strategically selecting the type of natural landscape that most efficiently provides urban ES given limited space available. This includes redesigning existing UGS according to the functionality of various natural elements alongside the evolving ecosystem service needs of the urban community. For instance, the roads and road dividers were initially landscaped with low-lying shrubs for their aesthetic values (Yuen 1996; Drillet et al. 2020). To enhance urban ES provision and maximise the functionality of the space, roadside greenery can be upgraded to incorporate more overstorey trees and multi-tiered vegetation to support greater biodiversity and improve air quality regulation (Drillet et al. 2020; National Parks Board 2020). Similar strategies have been suggested in a study in Porto, Portugal positing that regulatory ES provision in a land-sparse city could be optimised by taking into account both ES provision performance and spatial coverage of the proposed landscape to be constructed (Graça et al. 2018). The importance of land cover composition reinforces the nonlinear relationship between area of UGS and provision of ES (Grêt-Regamey et al. 2020), which is a key consideration for cities when maximising urban ES provision and maintaining equitable distribution.

Notwithstanding the host of benefits urban greening could bring, this process could potentially risk gentrification of the redeveloped environment and undesirably reinforcing socio-environmental inequity in cities (Garcia-Lamarca et al. 2021). Governments around the world have been increasingly drawn towards green boosterism to attract financial and human capital, or to pursue sustainable development (Hagbert et al. 2013; Zhang et al. 2018). However, living in a more environmentally designed neighbourhood has become an indicator of superior quality of life, which tends to serve mainly the high-income population, upsetting the social inclusiveness of sustainable development. This conflict between sustainable development and gentrification is evident in Victoria, Canada, where the conversion of urban voids into environmentally attractive landscapes has reduced housing affordability and reinforced socio-economic gaps between high and low-income neighbourhoods (Dale and Newman 2009). Similarly, social inequity in the city of Austin in Texas resulted from the absence of social equity discourse during its Smart Growth Plan in the mid-1990s, disproportionately disadvantaged the low-income, minority neighbourhoods (Garcia-Lamarca et al. 2021). In Singapore, despite the uniquely integrated social setting maintained through government policies, it is unlikely to be possible to fully preserve environmental equity against private interests in residential landscape developments. In fact, a few instances of eco-centric residential developments in Singapore have been reported to fetch prices close to a million dollars, significantly higher than other housing units of similar sizes and locations (Wong 2012; Heng 2015; Yeo and Heng 2015; Belcher et al. 2019; Tay 2020). While these cases have yet to make significant impact in disrupting the environmental equity in Singapore, it is crucial to maintain the balance between urban greening and social equity in a city's sustainable development to maximise the benefits of ESs across all socio-demographic communities.

Limitations

This study is subjected to several caveats. Firstly, due to the nature of the Gini coefficient calculation, only PM_{10} removal service could be evaluated. This limits the comprehensiveness of the vertical inequality assessment in affirming the overall equity in ES supply. Secondly, as the supplies of regulatory ESs in this study were all based on the land cover classifications generated by Gaw et al. (2019) with a reported overall accuracy of 79%, the spatial variation of ES supplies is subjected to error. However, the level of accuracy is in line with similar literature that perform high resolution land cover classification (Liu et al. 2017; Randall et al. 2019). Nonetheless, given a more accurate land use classification map for ES estimation, the socio-spatial relationship of urban regulatory ES distribution could be more noticeable.

Future work

Further research could consider the usage of decomposable proxies for regulatory ES supply to more comprehensively measure the vertical inequality in its distribution. Urban environmental equity can also be further explored through the supply of and demand for ES provision to better quantify the mismatch between what the population needs and how efficiently the city has managed to distribute their environmental resources.

In addition, the potential interaction between distributional and procedural equity as a result of Singapore's unique environmental governance paradigm could also provide alternative insights into environmental outcomes regarding urban ES supply and distribution. The environmental governance in Singapore has historically taken a top-down approach that has over time become progressively more consultative and participatory (Leitmann 1999; Han 2017). In the infancy of Singapore's environmental governance, the *Garden City* initiative was conceived with the intention of increasing Singapore's attractiveness to foreign capital by means of improving Singapore's living environment, therefore providing a workforce with high economic productivity (Savage 1998). This indicates little procedural equity in the decision-making process of environmental management in the past in part due to the need to optimally allocate land use to the scarcely available land spaces in Singapore. However, the progressive incorporation of consultative and participatory sessions in the urban planning process, although still largely routinised under the governmental arrangements, could improve procedural environmental equity and potentially contribute to better distributional environmental equity outcome.

CONCLUSION

The role of regulatory ESs in augmenting urban dwellers' quality of life and improving human well-being has increased the appeal of sustainable urban development to urban planners. However, the heterogeneity of urban sociodemographics has often led to environmental injustice in the forms of racism or classism. Singapore, as a highly urbanised and socio-demographically pluralistic society could potentially be enmeshed in this socio-environmental conflict. Nonetheless, through the application of horizontal and vertical inequality measures, our study shows that Singapore is capable of upholding environmental justice in the distribution of regulatory ES supply. Despite spatial variability in ES supply across Singapore's landscape, the relatively equitable distribution of urban regulatory ESs among Singapore residents of various socio-demographic characteristics is observed. This is likely attributed to Singapore's extensive efforts in increasing local UGS provision, the persistent dedication towards maintaining social harmony and the planned urban landscape, making Singapore a distinctive case study compared to the existing studies in environmental equity.

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REFERENCES

Aflaki, A., M. Mirnezhad, A. Ghaffarianhoseini, A. Ghaffarianhoseini, H. Omrany, Z.-H. Wang, and H. Akbari. 2017. Urban heat island mitigation strategies: A state-of-the-art review on Kuala Lumpur, Singapore and Hong Kong. *Cities* 62: 131–145. https://doi.org/10.1016/j.cities.2016.09.003.

Aghamohammadi, N., L. Ramakreshnan, C.S. Fong, and N.M. Sulaiman. 2020. Climate-related disasters and health impact in Malaysia. In *Extreme weather events and human health: International case studies*, ed. R. Akhtar, 247–263. Springer International Publishing. New York.

Akbari, H., C. Cartalis, D. Kolokotsa, A. Muscio, A.L. Pisello, F. Rossi, M. Santamouris, A. Synnefa, et al. 2016. Local climate change and urban heat island mitigation techniques-the state of the art. *Journal of Civil Engineering and Management* 22: 1–16. https://doi.org/10.3846/13923730.2015.1111934.

Andersson, E., J. Langemeyer, S. Borgström, T. McPhearson, D. Haase, J. Kronenberg, D.N. Barton, M. Davis, et al. 2019. Enabling green and blue infrastructure to improve contributions to human well-being and equity in urban systems. *BioScience* 69: 566–574. https://doi.org/10.1093/biosci/biz058.

ANSI S1.26. 1995. Method for calculation of the absorption of sou. https://infostore.saiglobal.com/en-us/standards/ansi-s1-26-1995-r2009–133119_SAIG_ASA_ASA_284420/

Beichler, S.A., O. Bastian, D. Haase, S. Heiland, N. Kabisch, and F. Müller. 2017. Does the ecosystem service concept reach its limits in urban environments? *Landscape Online* 51: 1–22. https://doi.org/10.3097/LO.201751.

Belcher, R.N., E. Suen, S. Menz, and T. Schroepfer. 2019. Shared landscapes increase condominium unit selling price in a high-density city. *Landscape and Urban Planning* 192: 103644. https://doi.org/10.1016/j.landurbplan.2019.103644.

Benra, F., and L. Nahuelhual. 2019. A trilogy of inequalities: Land ownership, forest cover and ecosystem services distribution. *Land Use Policy* 82: 247–257. https://doi.org/10.1016/j.landusepol.2018.12.020.

Biernacka, M., and J. Kronenberg. 2018. Classification of institutional barriers affecting the availability, accessibility and attractiveness of urban green spaces. *Urban Forestry & Urban Greening* 36: 22–33. https://doi.org/10.1016/j.ufug.2018.09.007.

Biernacka, M., and J. Kronenberg. 2019. *Urban green space availability accessibility and attractiveness and the delivery of ecosystem services* https://digitalcommons.lmu.edu/cate/vol12/iss1/5.12.

Blankenshipa, E.E., M.W. Perkinsb, and R.J. Johnsonc. 2002. The information-theoretic approach to model selection: Description and case study. *Conference on Applied Statistics in Agriculture*. https://doi.org/10.4148/2475-7772.1200.

Bottalico, F., G. Chirici, F. Giannetti, A. De Marco, S. Nocentini, E. Paoletti, F. Salbitano, G. Sanesi, et al. 2016. Air pollution removal by green infrastructures and urban forests in the city of florence. *Agriculture and Agricultural Science Procedia* 8: 243–251. https://doi.org/10.1016/j.aaspro.2016.02.099.

Boyce, J.K., K. Zwickl, and M. Ash. 2014. Three measures of environmental inequality. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.2638089.

Boyce, J.K., K. Zwickl, and M. Ash. 2016. Measuring environmental inequality. *Ecological Economics* 124: 114–123. https://doi.org/10.1016/j.ecolecon.2016.01.014.

Bravo, M.A., R. Anthopolos, M.L. Bell, and M.L. Miranda. 2016. Racial isolation and exposure to airborne particulate matter and ozone in understudied US populations: Environmental justice applications of downscaled numerical model output. *Environment International* 92–93: 247–255. https://doi.org/10.1016/j.envint.2016.04.008.

Brzoska, P., and A. Spāģe. 2020. From city- to site-dimension: assessing the urban ecosystem services of different types of green infrastructure. *Land* 9: 150. https://doi.org/10.3390/land9050150.

Capon, A. 2017. Harnessing urbanisation for human wellbeing and planetary health. *The Lancet Planetary Health* 1: e6–e7. https://doi.org/10.1016/S2542-5196(17)30005-0.

Carrière, S., R. Weigend Rodríguez, P. Pey, F. Pomponi, and S. Ramakrishna. 2020. Circular cities: The case of Singapore. *Built Environment Project and Asset Management* 10: 491–507. https://doi.org/10.1108/BEPAM-12-2019-0137.

Chan, F., J. Chuah, A. Ziegler, M. Dąbrowski, and V. Olli. 2018. Towards resilient flood risk management for Asian coastal cities: Lessons learned from Hong Kong and Singapore. *Journal of Cleaner Production* 187: 576–589. https://doi.org/10.1016/j.jclepro.2018.03.217.

Chew, V. 2009. *Development guide plans | Infopedia*. Singapore Infopedia. https://eresources.nlb.gov.sg/infopedia/articles/SIP_1371_2009-01-05.html

Chin, C., Z.Y. Thang, and S. Saju. 2019a. *Study on impact of noise annoyance from highway traffic in Singapore City*. 015001. https://doi.org/10.1121/2.0001116

Chin, C., Z.Y. Thang, and S. Saju. 2019b. Study on impact of noise annoyance from highway traffic in Singapore City. *178th Meeting of the Acoustical Society of America*, *39*, 015001. https://doi.org/10.1121/2.0001116

Chow, W.T.L., B.D. Cheong, and B.H. Ho. 2016. A multimethod approach towards assessing urban flood patterns and its associated vulnerabilities in Singapore. *Advances in Meteorology* 2016: e7159132. https://doi.org/10.1155/2016/7159132.

Chow, W.T.L., and M. Roth. 2006a. Temporal dynamics of the urban heat island of Singapore. *International Journal of Climatology* 26: 2243–2260. https://doi.org/10.1002/joc.1364.

Chow, W.T.L., and M. Roth. 2006b. Temporal dynamics of the urban heat island of Singapore. *International Journal of Climatology* 26: 2243–2260. https://doi.org/10.1002/joc.

Cole, H.V.S., M. Garcia Lamarca, J.J.T. Connolly, and I. Anguelovski. 2017. Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech-2017-209201.

Cortinovis, C., and D. Geneletti. 2018. Ecosystem services in urban plans: What is there, and what is still needed for better decisions. *Land Use Policy* 70: 298–312. https://doi.org/10.1016/j.landusepol.2017.10.017.

Cox, D.T.C., D.F. Shanahan, H.L. Hudson, R.A. Fuller, and K.J. Gaston. 2018. The impact of urbanisation on nature dose and the implications for human health. *Landscape and Urban Planning* 179: 72–80. https://doi.org/10.1016/j.landurbplan.2018.07.013.

Dale, A., and L.L. Newman. 2009. Sustainable development for some: Green urban development and affordability. *Local Environment* 14: 669–681. https://doi.org/10.1080/13549830903089283.

De Carvalho, R.M., and C.F. Szlafsztein. 2019. Urban vegetation loss and ecosystem services: The influence on climate regulation and noise and air pollution. *Environmental Pollution* 245: 844–852. https://doi.org/10.1016/j.envpol.2018.10.114.

Demuzere, M., K. Orru, O. Heidrich, E. Olazabal, D. Geneletti, H. Orru, A.G. Bhave, N. Mittal, et al. 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. *Journal of Environmental Management* 146: 107–115. https://doi.org/10.1016/j.jenvman.2014.07.025.

Department of Statistics. 2020. *Population and Population Structure—Latest Data*. Department of Statistics Singapore. http://www.singstat.gov.sg/find-data/search-by-theme/population/population-and-population-structure/latest-data

Department of Statistics. 2021. *Households—Latest Data*. Department of Statistics Singapore. http://www.singstat.gov.sg/find-data/search-by-theme/households/households/latest-data

Dissegna, M.A., T. Yin, S. Wei, D. Richards, and A. Grêt-Regamey. 2019. 3-D reconstruction of an urban landscape to assess the influence of vegetation in the radiative budget. *Forests* 10: 700. https://doi.org/10.3390/f10080700.

Downey, L. 2005. Assessing environmental inequality: How the conclusions we draw vary according to the definitions we employ. *Sociological Spectrum* 25: 349–369. https://doi.org/10.1080/027321790518870.

Drillet, Z., T.K. Fung, R.A.T. Leong, U. Sachidhanandam, P. Edwards, and D. Richards. 2020. Urban vegetation types are not perceived equally in providing ecosystem services and disservices. *Sustainability* 12: 2076. https://doi.org/10.3390/su12052076.

Dronova, I. 2017. Environmental heterogeneity as a bridge between ecosystem service and visual quality objectives in management, planning and design. *Landscape and Urban Planning* 163: 90–106. https://doi.org/10.1016/j.landurbplan.2017.03.005.

Elmqvist, T., H. Setälä, S. Handel, S. van der Ploeg, J. Aronson, J. Blignaut, E. Gómez-Baggethun, D. Nowak, et al. 2015. Benefits of restoring ecosystem services in urban areas. *Current Opinion in Environmental Sustainability* 14:101–108. https://doi.org/10.1016/j.cosust.2015.05.001.

Ernstson, H. 2013. The social production of ecosystem services: A framework for studying environmental justice and ecological complexity in urbanized landscapes. *Landscape and Urban Planning* 109:7–17. https://doi.org/10.1016/j.landurbplan.2012.10.005.

Escobedo, F.J., and D.J. Nowak. 2009. Spatial heterogeneity and air pollution removal by an urban forest. *Landscape and Urban Planning* 90:102–110. https://doi.org/10.1016/j.landurbplan.2008.10.021.

Esri. n.d.-a. *How Hot Spot Analysis (Getis-Ord Gi*) works*. ArcGIS Desktop. https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-statistics-toolbox/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm

Esri. n.d.-b. *Incremental Spatial Autocorrelation*. ArcGIS Desktop. https://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-statistics-toolbox/incremental-spatial-autocorrelation.htm

Fernández-Álvarez, R. 2017. Inequitable distribution of green public space in the Mexico City: An environmental injustice case. *Economía Sociedad y Territorio*. https://doi.org/10.22136/est002017697.

Fielding, J., and K. Burningham. 2005. Environmental inequality and flood hazard. *Local Environment* 10: 379–395. https://doi.org/10.1080/13549830500160875.

Fisher, B., R.K. Turner, and P. Morling. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643–653. https://doi.org/10.1016/j.ecolecon.2008.09.014.

Friedman, R.S., E.A. Law, N.J. Bennett, C.D. Ives, J.P.R. Thorn, and K.A. Wilson. 2018. How just and just how? A systematic review of social equity in conservation research. *Environmental Research Letters* 13: 053001. https://doi.org/10.1088/1748-9326/aabcde.

Fung, T.K., D.R. Richards, R.A.T. Leong, S. Ghosh, C.W.J. Tan, Z. Drillet, K.L. Leong, and P.J. Edwards. 2021. Litter decomposition and infiltration capacities in soils of different tropical urban land covers. *Urban Ecosystems*. https://doi.org/10.1007/s11252-021-01126-2.

Galipaud, M., M.A.F. Gillingham, M. David, and F.-X. Dechaume-Moncharmont. 2014. Ecologists overestimate the importance of predictor variables in model averaging: A plea for cautious interpretations. *Methods in Ecology and Evolution* 5: 983–991. https://doi.org/10.1111/2041-210X.12251.

Garcia-Lamarca, M., I. Anguelovski, H. Cole, J.J. Connolly, L. Argüelles, F. Baró, S. Loveless, Pérez. del Pulgar, et al. 2021. Urban green boosterism and city affordability: For whom is the 'branded' green city? *Urban Studies* 58: 90–112. https://doi.org/10.1177/0042098019885330.

Gaw, L.Y., A.T. Yee, and D.R. Richards. 2019. A high-resolution map of Singapore's terrestrial ecosystems. *Data* 4: 116. https://doi.org/10.3390/data4030116.

Geneletti, D., C. Cortinovis, L. Zardo, and B.A. Esmail. 2020. *Planning for ecosystem services in cities*. New York: Springer International Publishing.

Graça, M., P. Alves, J. Gonçalves, D.J. Nowak, R. Hoehn, P. Farinha-Marques, and M. Cunha. 2018. Assessing how green space types affect ecosystem services delivery in Porto, Portugal. *Landscape and Urban Planning* 170: 195–208. https://doi.org/10.1016/j.landurbplan.2017.10.007.

Grêt-Regamey, A., M. Galleguillos-Torres, A. Dissegna, and B. Weibel. 2020. How urban densification influences ecosystem services: A comparison between a temperate and a tropical city. *Environmental Research Letters* 15: 075001. https://doi.org/10.1088/1748-9326/ab7acf.

Grineski, S.E., T.W. Collins, and D.X. Morales. 2017. Asian Americans and disproportionate exposure to carcinogenic hazardous air pollutants: A national study. *Social Science & Medicine* 185: 71–80. https://doi.org/10.1016/j.socscimed.2017.05.042.

Gryning, S.-E., and N. Chaumerliac, eds. 1998. *Air pollution modeling and its application XII*. New York: Springer.

Guerra, C.A., T. Pinto-Correia, and M.J. Metzger. 2014. Mapping soil erosion prevention using an ecosystem service modeling framework for integrated land management and policy. *Ecosystems* 17: 878–889. https://doi.org/10.1007/s10021-014-9766-4.

Haaland, C., and C.K. van den Bosch. 2015. Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban Forestry & Urban Greening* 14: 760–771. https://doi.org/10.1016/j.ufug.2015.07.009.

Haase, D., N. Larondelle, E. Andersson, M. Artmann, S. Borgström, J. Breuste, E. Gomez-Baggethun, et al. 2014. A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. *Ambio* 43: 413–433.https://doi.org/10.1007/s13280-014-0504-0

Hagbert, P., M. Mangold, and P. Femenías. 2013. Paradoxes and possibilities for a 'green' housing sector: A swedish case. *Sustainability* 5: 2018–2035. https://doi.org/10.3390/su5052018.

Haines-Young, R., and M. Potschin. 2017. Common International Classification of Ecosystem Services (CICES) V5.1 guidance on the application of the revised structure. *One Ecosystem* 31: 15–89.

Han, H. 2017. Singapore, a garden city: Authoritarian environmentalism in a developmental state. *The Journal of Environment & Development* 26: 3–24. https://doi.org/10.1177/1070496516677365.

Hansen, R., N. Frantzeskaki, T. McPhearson, E. Rall, N. Kabisch, A. Kaczorowska, J.-H. Kain, M. Artmann, et al. 2015. The uptake of the ecosystem services concept in planning discourses of European and American cities. *Ecosystem Services* 12: 228–246. https://doi.org/10.1016/j.ecoser.2014.11.013.

Harrison, R., R. Clark, and G. Stankey. 1980a. *Predicting impact of noise on recreationists*.

Harrison, R. T., R. N. Clark, and G. H. Stankey 1980b. Predicting impact of noise on recreationists. *Predicting Impact of Noise on Recreationists.* https://www.cabdirect.org/cabdirect/abstract/19811878509

Heng, J. 2015. *5-Room Punggol Flat Sold For $760,000*. The Straits Times. https://www.straitstimes.com/singapore/5-room-punggol-flat-sold-for-760000

Heynen, N.C. 2003. The scalar production of injustice within the urban forest. *Antipode* 35: 980–998. https://doi.org/10.1111/j.1467-8330.2003.00367.x.

Heynen, N., H.A. Perkins, and P. Roy. 2006. The Political ecology of uneven urban green space: The impact of political economy on race and ethnicity in producing environmental inequality in milwaukee. *Urban Affairs Review* 42: 3–25. https://doi.org/10.1177/1078087406290729.

Hu, X., W. Hong, R. Qiu, T. Hong, C. Chen, and C. Wu. 2015. Geographic variations of ecosystem service intensity in Fuzhou City, China. *Science of the Total Environment* 512–513: 215–226. https://doi.org/10.1016/j.scitotenv.2015.01.035.

Kaczynski, A., G. Besenyi, S. Wilhelm Stanis, J. Koohsari, K. Oestman, R. Bergstrom, L. Potwarka, and R. Reis. 2014. Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *International Journal of Behavioral Nutrition and Physical Activity* 11: 146. https://doi.org/10.1186/s12966-014-0146-4.

Kelly-Reif, K., and S. Wing. 2016. Urban-rural exploitation: An underappreciated dimension of environmental injustice. *Journal of Rural Studies* 47: 350–358. https://doi.org/10.1016/j.jrurstud.2016.03.010.

Kim, J., and P.A. Jargowsky. 2009. The GINI coefficient and segregation on a continuous variable. In *Occupational and residential segregation*, ed. Y. Flückiger, S.F. Reardon, and J. Silber. Bingley: Emerald Group Publishing Limited.

Kronenberg, J., A. Haase, E. Łaszkiewicz, A. Antal, A. Baravikova, M. Biernacka, D. Dushkova, R. Filčak, et al. 2020. Environmental justice in the context of urban green space availability, accessibility, and attractiveness in postsocialist cities. *Cities* 106: 102862. https://doi.org/10.1016/j.cities.2020.102862.

Krug, J., M. Koehl, and D. Kownatzki. 2012. Revaluing unmanaged forests for climate change mitigation. *Carbon Balance and Management* 7: 11. https://doi.org/10.1186/1750-0680-7-11.

Langemeyer, J., and J.J.T. Connolly. 2020. Weaving notions of justice into urban ecosystem services research and practice. *Environmental Science & Policy* 109: 1–14. https://doi.org/10.1016/j.envsci.2020.03.021.

Leitmann, J. 1999. Integrating the environment in urban development: Singapore as a model of good practice. *Urban Development Division, World Bank, Washington* 29: 1–58.

Li, J., and F. Tartarini. 2020. Changes in air quality during the COVID-19 lockdown in Singapore and associations with human mobility trends. *Aerosol and Air Quality Research* 20: 1748–1758. https://doi.org/10.4209/aaqr.2020.06.0303.

Li, T., C. Qiu, H. Cheng, and H.O. Ikhumhen. 2016. Application of Environmental Gini Coefficient (EGC) in allocating SO2 discharge permit: A case study of SO2 total mass control in Anshan China. *Nature Environment and Pollution Technology* 15: 9.

Liao, K.-H. 2019. The socio-ecological practice of building blue-green infrastructure in high-density cities: What does the ABC Waters Program in Singapore tell us? *Socio-Ecological Practice Research* 1: 67–81. https://doi.org/10.1007/s42532-019-00009-3.

Lim, T., C.-H. Leong, and F. Suliman. 2019. Managing Singapore's residential diversity through ethnic integration policy. *Equality, Diversity and Inclusion: An International Journal* 39: 109–125. https://doi.org/10.1108/EDI-05-2019-0168.

Liu, X., J. He, Y. Yao, J. Zhang, H. Liang, H. Wang, and Y. Hong. 2017. Classifying urban land use by integrating remote sensing and social media data. *International Journal of Geographical Information Science* 31: 1675–1696. https://doi.org/10.1080/13658816.2017.1324976.

Lourenço, I.B., A.K. Beleño de Oliveira, L.S. Marques, A.A. Quintanilha Barbosa, A.P. Veról, P.C. Magalhães, and M.G. Miguez. 2020. A framework to support flood prevention and mitigation in the landscape and urban planning process regarding water dynamics. *Journal of Cleaner Production* 277: 122983. https://doi.org/10.1016/j.jclepro.2020.122983.

Ma, H., and T. Yano. 2004. An experiment on auditory and non-auditory disturbances caused by railway and road traffic noises in outdoor conditions. *Journal of Sound and Vibration* 277: 501–509. https://doi.org/10.1016/j.jsv.2004.03.011.

Manes, F., V. Silli, E. Salvatori, G. Incerti, G. Galante, L. Fusaro, and C. Perrino. 2014. Urban ecosystem services: tree diversity and stability of PM10 removal in the metropolitan area of Rome. *Annali Di Botanica*. https://doi.org/10.4462/annbotrm-11746.

Miguez, M.G., A.P. Veról, P. Roberto, and F. Carneiro. n.d.. *2 Sustainable drainage systems: An integrated approach, combining hydraulic engineering design, urban land control and river revitalisation aspects*

Millimet, D.L., and D. Slottje. 2002. An environmental Paglin-Gini. *Applied Economics Letters* 9: 271–274. https://doi.org/10.1080/13504850110062031.

Ministry of National Development, and Ministry of the Environment and Water Resources. 2009. *The inter-ministerial committee for sustainable development unveils blueprint for a sustainable Singapore* [Press Release]. https://www.nas.gov.sg/archivesonline/data/pdfdoc/MSE_20090427001.pdf

Ministry of the Environment and Water Resources. 2016. *Our home, our environment, our future: sustainable Singapore blueprint 2015*. https://www.nccs.gov.sg/docs/default-source/default-document-library/sustainable-singapore-blueprint-2015.pdf

Moore, I.D., and G.J. Burch. 1986. Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal* 50: 1294–1298. https://doi.org/10.2136/sssaj1986.03615995005000050042x.

Morello-Frosch, R.A. 2002. Discrimination and the political economy of environmental inequality. *Environment and Planning C: Government and Policy* 20: 477–496. https://doi.org/10.1068/c03r.

National Archives Singapore. n.d.. IMCSD invites views on sustainable development for Singapore. Retrieved 11 February 2022, from https://www.nas.gov.sg/archivesonline/data/pdfdoc/20080813994.htm

National Environment Agency. 2020. *Air Pollutant—Particulate Matter PM10 (24-hr Mean -99th Percentile)*. https://data.gov.sg/dataset/air-pollutant-particulate-matter-pm10

National Environment Agency. 2021. *Air Quality*. https://www.nea.gov.sg/our-services/pollution-control/air-pollution/air-quality

National Parks Board. 2020. *Nature Ways*. Gardens, Parks & Nature. https://www.nparks.gov.sg/gardens-parks-and-nature/nature-ways

Newell, P. 2005. Race, class and the global politics of environmental inequality. *Global Environmental Politics* 5: 70–94. https://doi.org/10.1162/1526380054794835.

Nghiem, T.P.L., Y. Zhang, R.R.Y. Oh, C. Chang, C.L.Y. Tan, D.F. Shannahan, B.B. Lin, K.J. Gaston, et al. 2021. Equity in green and blue space availability in Singapore. *Landscape and Urban Planning* 210: 104083.

Nyelele, C., and C.N. Kroll. 2020. The equity of urban forest ecosystem services and benefits in the Bronx NY. *Urban Forestry & Urban Greening* 53: 126723. https://doi.org/10.1016/j.ufug.2020.126723.

Onishi, A., X. Cao, T. Ito, F. Shi, and H. Imura. 2010. Evaluating the potential for urban heat-island mitigation by greening parking lots. *Urban Forestry & Urban Greening* 9: 323–332. https://doi.org/10.1016/j.ufug.2010.06.002.

Panagos, P., P. Borrelli, K. Meusburger, B. Yu, A. Klik, K. Jae Lim, J.E. Yang, J. Ni, et al. 2017. Global rainfall erosivity assessment based on high-temporal resolution rainfall records. *Scientific Reports* 7: 4175. https://doi.org/10.1038/s41598-017-04282-8.

Pandeya, B., W. Buytaert, Z. Zulkafli, T. Karpouzoglou, F. Mao, and D.M. Hannah. 2016. A comparative analysis of ecosystem services valuation approaches for application at the local scale and in data scarce regions. *Ecosystem Services* 22: 250–259. https://doi.org/10.1016/j.ecoser.2016.10.015.

Peng, N. 2019. Inequality and the social compact in Singapore: Macro Trends versus lived realities. *Journal of Southeast Asian Economies* 36: 355–379.

Pham, T.-T.-H., P. Apparicio, A.-M. Séguin, S. Landry, and M. Gagnon. 2012. Spatial distribution of vegetation in Montreal: An uneven distribution or environmental inequity? *Landscape and Urban Planning* 107: 214–224. https://doi.org/10.1016/j.landurbplan.2012.06.002.

Phang, S.Y., and M. Helble. 2016. *Housing Policies in Singapore* (SSRN Scholarly Paper ID 2753487). *Social Science Research Network*. https://doi.org/10.2139/ssrn.2753487.

Prime Minister's Office, Department of Statistics, Ministry of Home Affairs, Immigration & Checkpoints Authority, & Ministry of Manpower. 2021. *Population in Brief 2021*. https://www.population.gov.sg/files/media-centre/publications/population-in-brief-2021.pdf

Quah, E., and T.L. Boon. 2003. The economic cost of particulate air pollution on health in Singapore. *Journal of Asian Economics* 14: 73–90. https://doi.org/10.1016/S1049-0078(02)00240-3.

R Core Team. 2020. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Randall, M., R. Fensholt, Y. Zhang, and M. Bergen Jensen. 2019. Geographic Object Based Image Analysis of WorldView-3 Imagery for Urban Hydrologic Modelling at the Catchment Scale. *Water* 11: 1133. https://doi.org/10.3390/w11061133.

Reed, S.E., J.L. Boggs, and J.P. Mann. 2012. A GIS tool for modeling anthropogenic noise propagation in natural ecosystems. *Environmental Modelling & Software* 37: 1–5. https://doi.org/10.1016/j.envsoft.2012.04.012.

Renard, K. G., USA, and USA (Eds.). 1997. *Predicting soil erosion by water: A guide to conservation planning with the revised universal soil loss equation (RUSLE)*.

Richards, D. R., Tan, B. A., Gaw, L. Y.-F., and Masoudi, M. 2021. *NCS2020: An R package for modelling ecosystem service provision in Singapore.* Github. https://github.com/drexrichards/ncs2020

Richards, D., and Wang, J. W. 2020a. Fusing street level photographs and satellite remote sensing to map leaf area index. *Ecological Indicators*, *115*(2019), 106342. https://doi.org/10.1016/j.ecolind.2020a.106342

Richards, D., and J.W. Wang. 2020b. Fusing street level photographs and satellite remote sensing to map leaf area index. *Ecological Indicators* 115: 106342. https://doi.org/10.1016/j.ecolind.2020.106342.

Rigolon, A., M. Browning, K. Lee, and S. Shin. 2018. Access to Urban Green Space in Cities of the Global South: A Systematic Literature Review. *Urban Science* 2: 67. https://doi.org/10.3390/urbansci2030067.

Riley, C.B., and M.M. Gardiner. 2020. Examining the distributional equity of urban tree canopy cover and ecosystem services across United States cities. *PLoS ONE* 15: e0228499. https://doi.org/10.1371/journal.pone.0228499.

Rój, J. 2020. Inequality in the Distribution of Healthcare Human Resources in Poland. *Sustainability* 12: 2043. https://doi.org/10.3390/su12052043.

Rushayati, S.B., L.B. Prasetyo, N. Puspaningsih, and E. Rachmawati. 2016. Adaptation Strategy Toward Urban Heat Island at Tropical Urban Area. *Procedia Environmental Sciences* 33: 221–229. https://doi.org/10.1016/j.proenv.2016.03.073.

Savage, V. R. 1998. Singapore, the Planned City State: Government Intervention in Nation Building. In *Regional Development and Planning for the 21st Century*. Routledge.

Schell, C. J., Dyson, K., Fuentes, T. L., Roches, S. D., Harris, N. C., Miller, D. S., Woelfle-Erskine, C. A et al. 2020. The ecological and evolutionary consequences of systemic racism in urban environments. *Science*, *369*(6510). https://doi.org/10.1126/science.aay4497

Scherer, L., P. Behrens, A. de Koning, R. Heijungs, B. Sprecher, and A. Tukker. 2018. Trade-offs between social and environmental Sustainable Development Goals. *Environmental Science & Policy* 90: 65–72. https://doi.org/10.1016/j.envsci.2018.10.002.

Schipperijn, J., E. Cerin, M.A. Adams, R. Reis, G. Smith, K. Cain, L.B. Christiansen, D. van Dyck, et al. 2017. Access to parks and physical activity: An eight country comparison. *Urban Forestry & Urban Greening* 27: 253–263. https://doi.org/10.1016/j.ufug.2017.08.010.

Seik, F.T. 1996. Urban environmental policy—the use of regulatory and economic instruments in Singapore. *Habitat International* 20: 5–22. https://doi.org/10.1016/0197-3975(95)00031-3.

Setiowati, R., H.S. Hasibuan, and R.H. Koestoer. 2018. Green open space masterplan at Jakarta Capital City, Indonesia for climate change mitigation. *IOP Conference Series: Earth and Environmental Science* 200: 012042. https://doi.org/10.1088/1755-1315/200/1/012042.

Singapore Green Plan. 2021. *Singapore Green Plan*. https://www.greenplan.gov.sg/

Sister, C., J. Wolch, and J. Wilson. 2010. Got green? Addressing environmental justice in park provision. *GeoJournal* 75: 229–248.

Sun, T., H. Zhang, Y. Wang, X. Meng, and C. Wang. 2010. The application of environmental Gini coefficient (EGC) in allocating wastewater discharge permit: The case study of watershed total mass control in Tianjin, China. *Resources, Conservation and Recycling* 54: 601–608. https://doi.org/10.1016/j.resconrec.2009.10.017.

Symonds, M.R.E., and A. Moussalli. 2011. A brief guide to model selection, multimodel inference and model averaging in behavioural ecology using Akaike's information criterion. *Behavioral Ecology and Sociobiology* 65: 13–21. https://doi.org/10.1007/s00265-010-1037-6.

Tan, K.W. 2006. A greenway network for singapore. *Landscape and Urban Planning* 76: 45–66. https://doi.org/10.1016/j.landurbplan.2004.09.040.

Tan, P.Y., and R. Samsudin. 2017. Effects of spatial scale on assessment of spatial equity of urban park provision. *Landscape and Urban Planning* 158: 139–154. https://doi.org/10.1016/j.landurbplan.2016.11.001.

Tan, P.Y., J. Wang, and A. Sia. 2013. Perspectives on five decades of the urban greening of Singapore. *Cities* 32: 24–32. https://doi.org/10.1016/j.cities.2013.02.001.

Tan, P.Y., J. Zhang, M. Masoudi, J.B. Alemu, P.J. Edwards, A. Grêt-Regamey, D.R. Richards, Saunders, et al. 2020. A conceptual framework to untangle the concept of urban ecosystem services. *Landscape and Urban Planning* 200: 103837. https://doi.org/10.1016/j.landurbplan.2020.103837.

Tay, T. 2020. *Dawson HDB Flats Cross Million-Dollar Threshold Soon After MOP*. EdgeProp. https://www.edgeprop.sg/property-news/dawson-hdb-flats-cross-million-dollar-threshold-soon-after-mop

Teo, Y. Y. 2019. *This is What Inequality Looks Like* (New Edition). Ethos Books.

The World Bank. n.d.. *Population density (people per sq. Km of land area)—South Asia, East Asia & Pacific | Data*. Retrieved 13 December 2021, from https://data.worldbank.org/indicator/EN.POP.DNST?locations=8S-Z4&most_recent_value_desc=true

Tortajada, C. 2006. Water Management in Singapore. *International Journal of Water Resources Development* 22: 227–240. https://doi.org/10.1080/07900620600691944.

United Nations. 2017. Transforming Our World: The 2030 Agenda for Sustainable Development. In W. Rosa (Ed.), *A New Era in Global Health*. Springer Publishing Company. https://doi.org/10.1891/9780826190123.ap02

United Nations, Department of Economic and Social Affairs, & Population Division. 2019. *World urbanization prospects: The 2018 revision*.

URA. 2014. *Landscaping for Urban Spaces and High- Rises (LUSH) 2.0 Programme: Landscape Replacement Policy for Strategic Areas*.

Urban Redevelopment Agency. 2014. *Landscaping for Urban Spaces and High-Rises (LUSH) 2.0 Programme: Landscape Replacement Policy for Strategic Areas*. https://www.ura.gov.sg/Corporate/Guidelines/Circulars/dc14-12-original

USDA. 1986. *Urban Hydrology for Small Watersheds. In United States Department of Agriculture*. (Issue Technical Release 55 (TR-55)).

Van der Knijff, J., Jones, R., and Montanarella, L. 2000. Soil Erosion Risk Assessment in Europe. *Soil Erosion Risk Assessment in Europe*.

Venter, Z.S., C.M. Shackleton, F. Van Staden, O. Selomane, and V.A. Masterson. 2020. Green Apartheid: Urban green infrastructure remains unequally distributed across income and race geographies in South Africa. *Landscape and Urban Planning* 203: 103889. https://doi.org/10.1016/j.landurbplan.2020.103889.

Wang, Y., U. Berardi, and H. Akbari. 2016. Comparing the effects of urban heat island mitigation strategies for Toronto, Canada. *Energy and Buildings* 114: 2–19. https://doi.org/10.1016/j.enbuild.2015.06.046.

Wischmeier, W. H., and Smith, D. D. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. Department of Agriculture, Science and Education Administration.

Wong, C.M.L. 2012. The Developmental State in Ecological Modernization and the Politics of Environmental Framings: The Case of Singapore and Implications for East Asia. *Nature and Culture* 7: 95–119. https://doi.org/10.3167/nc.2012.070106.

Wong, L. 2018. "Debate on President's Address." Singapore. Parliament. Official Report, 94(76). 13th Parliament, 2nd session. https://sprs.parl.gov.sg/search/fullreport?sittingdate=17-5-2018.

Wu, J., Q. He, Y. Chen, J. Lin, and S. Wang. 2020. Dismantling the fence for social justice? Evidence based on the inequity of urban green space accessibility in the central urban area of Beijing. *Environment and Planning B: Urban Analytics and City Science* 47: 626–644. https://doi.org/10.1177/2399808318793139.

Yap, J., Y. Ng, K.K. Yeo, A. Sahlén, C.S.P. Lam, V. Lee, and S. Ma. 2019. Particulate air pollution on cardiovascular mortality in the tropics: Impact on the elderly. *Environmental Health* 18: 34. https://doi.org/10.1186/s12940-019-0476-4.

Yeo, M. T. 2019. From garden city to city in a garden and beyond. In T. Schröpfer and S. Menz (Eds.), *Dense and Green Building Typologies: Research, Policy and Practice Perspectives* (pp. 21–25). Springer. https://doi.org/10.1007/978-981-13-0713-3_5

Yeo, S. J., and Heng, J. 2015. *Pinnacle@Duxton flat fetches resale price of $900,000*. The Straits Times. https://www.straitstimes.com/singapore/housing/pinnacleduxton-flat-fetches-resale-price-of-900000

Yuen, B. 1996. Creating the Garden City: The Singapore Experience. *Urban Studies* 33: 955–970. https://doi.org/10.1080/0042098965001168l.

Zhang, L., J. Wu, and H. Liu. 2018. Policies to enhance the drivers of green housing development in China. *Energy Policy* 121: 225–235. https://doi.org/10.1016/j.enpol.2018.06.029.

Zheng, X., T. Xia, X. Yang, T. Yuan, and Y. Hu. 2013. The land Gini coefficient and its application for land use structure analysis in China. *PLoS ONE* 8: e76165. https://doi.org/10.1371/journal.pone.0076165.

Zhu, Y., M. Ke, and Z. Xuyao 2020. *Air pollution and mobility in Singapore during COVID-19 pandemic*. 16

Zinke, P.J. 1967. Forest interception studies in the United States. In *Forest hydrology*, ed. W.E. Sopper and H.W. Lull, 131–161. Pergamon Press.

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