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Blue-space availability, environmental quality and amenity use across contrasting socioeconomic contexts

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A R T I C L E I N F O

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A B S T R A C T

Over 60% of the global population are expected to live in urban areas by 2050. Urban blue spaces are critical for biodiversity, provide a range of ecosystem services, and can promote human health and wellbeing. Despite this, access to blue space is often unequally distributed across socioeconomic gradients, and the availability of quality blue space could extend to environmental justice issues. Three stages of analysis were carried out in Mexico City, Mexico and Bristol, UK to (i) assess associations between blue space and socioeconomic metrics at a regional scale, (ii) apply a rapid assessment tool to assess amenity, access and environmental quality, (iii) consider local quality across socioeconomic gradients at a regional scale. Still water availability was indicative of higher socioeconomic status, but contrasting city evolutions underpinned differences. Locally, there were environmental gradients from more complex to disturbed habitats that influenced potential wellbeing and amenity benefits. In combination, this may exacerbate inequalities and risk increasing ecosystem disservices. If cities are to be socially, and environmentally resilient to higher levels of disturbance in the future, healthy ecosystems will be key. However, further research is needed to address various dimensions of injustice in urban areas beyond blue space distribution.

2. Introduction

Global urban land coverage is set to increase by 1.2 million km^2 by 2030 (Seto et al., 2012), and over 60% of the population are expected to live in urban areas by 2050 (UN, 2018). The greatest urban population growth is predicted in lower income economies, with the most urbanized regions including Latin America and the Caribbean (81% of its population living in urban areas in 2018) and Europe (74%; UN, 2018). An expanding urban population and land coverage has been demonstrated to increase habitat fragmentation, reduce habitat complexity, lower water quality, increase human disturbance and encourage the establishment of non-native taxa in freshwater (Gál et al., 2019) causing a reduction in urban blue space quality (McKinney, 2008). Blue space represents all surface aquatic habitats such as rivers, streams, ponds, lakes, canals, ditches and drains located in urban public and private spaces (Raymond et al., 2016), which have significantly declined in

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abundance across urban landscapes in the last 100 years as a result of infilling, culverting, neglect and over-abstraction (e.g., Mexico City; Romero Lankao, 2010).

Despite the reduction in blue space presence, such spaces can play an important role in the positive perception of nature across urban landscapes as water provides opportunities for relaxation, reducing stress, and improving health, mental and physical wellbeing (Higgins et al., 2019; Völker et al., 2018; Völker & Kistemann, 2011). Urban blue spaces are used as meeting points for social activities and can enhance social integration as they provide a space for community building, social contacts and collective work (Armstrong, 2000; Leyden, 2003). In some cases, the presence of water is the most influential environmental attribute for establishing the price of real estate (Bourassa et al., 2004) and more generally, there is often an expected correlation between wealth and biodiversity; the 'luxury effect' (Hope et al., 2003). Alongside important cultural ecosystem services, blue spaces can also provide sites for biodiversity (Hill et al., 2016), flood alleviation (Lundy & Wade, 2011), and climate change (carbon sequestration; Downing et al., 2008) and urban heat island mitigation (Sun et al., 2012).

The societal benefits of ecosystems services provided by blue or green space do not however benefit all people in the same way, and depends upon social and political processes that model their generation, distribution and related values (Ernstson, 2013; Heynen, 2003). In addition, while focusing on urban green processes, Anguelovski et al. (2020) suggest that these green interventions tend to leave aside issues of exclusion, gentrification and displacement. Similarly, as blue and green infrastructure become a key element in urban resilience strategies, evidence suggests that they are often undermined by environmental injustices (Anguelovski et al., 2019; Shokry et al., 2020).

An unequal distribution may be further confounded by the quality of the ecosystem service provision, and the intactness of the environment (Baró et al., 2019). To this end, possible ecosystem disservices, often arising from degraded ecosystems may also occur. For example, there may be an increased likelihood of insect-borne disease (Lõhmus & Balbus, 2015) or the association of some water body types (e.g. canals) as spaces of fear and risk (Pitt, 2018). Similarly, flood alleviation is contingent on the location of wetlands within a catchment (Holden & Burt, 2003), and restored or newly created wetlands on former agricultural land can exacerbate nutrient enrichment (Klimas et al., 2016).

From an ecological perspective, blue spaces in urban areas have been typically found to support a limited biodiversity compared to rural freshwaters (e.g., Roy et al. 2003) and are increasingly similar in their compositions (McKinney, 2006). Although, urban ponds have been demonstrated to support a comparable diversity to non-urban ponds and have heterogeneous macroinvertebrate communities (Hill, Chadd, et al., 2016; Thornhill, Batty, Death, et al., 2017). Furthermore, urban blue space can act as refuges for a wide range of freshwater flora and fauna surrounded by an inhospitable urban landscape (Chester & Robson, 2013), and with careful management can provide sites of high ecological quality (Geist & Hawkins, 2016). These habitats can act as stepping stones between more natural freshwater habitats, although urban blue space may also act as an ecological trap providing unsuitable habitat (Villalobos-Jimenez et al., 2016). Given the reduced abundance of blue space, habitat connectivity (blue space spatial structure) is likely to play an increasingly important role in the distribution, persistence and diversity of biotic communities across urban areas (LaPoint et al., 2015). Accurately quantifying blue space abundance and spatial structure will enable more directed and effective biodiversity conservation measures to be employed.

Notwithstanding the clear importance of urban blue space for society, these spaces are commonly considered a subcategory under the umbrella of greenspaces (Haeffner et al., 2017), and there has been little systematic assessment of the availability of surface waters in urban areas, especially in low-mid income regions (Labib, Lindley and Huck, 2020). Given the (1) increasing population and development pressures on social and ecological systems (e.g., Reid et al., 2019) and (2) the importance of blue space for ecology and society, understanding the distribution and access to urban blue space for citizens, and their contribution to increasing social-ecological resilience in urban space is highly relevant. In the present study, a comparable analyses were undertaken in Bristol, UK and Mexico City, Mexico, two contrasting cities that differ considerably in their economic, political, social and environmental contexts, and two participants in the 100 Resilient Cities project (Rockefeller Foundation, 2020). Here we assessed (i) whether blue space availability was indicative of socioeconomic status at a regional (catchment) scale, (ii) covariance between ecological and social (amenity) characteristics at a local, site-scale, and (iii) patterns between local social-ecological factors and regional socioeconomic status.

3. Methods

3.1. Study areas

3.1.1. Mexico city

Mexico City is located in the basin of Mexico, an area of approximately 9600 km^2 and is at an elevation of 2240 m.a.s.l (Mazari-Hiriart et al., 2019). Mexico City has a sub-tropical climate which broadly shifts between a dry (November to April) and wet season (peaking June to September). Annual average rainfall is around 700 mm. Water supply to inhabitants of the Mexico City (approximately 9 million residents), is predominately sourced through groundwater abstraction, with more than 3500 registered wells across the city (Carrera-Hernández & Gaskin, 2007); water availability is estimated as 55 m^3/inhabitant/year (Comisión Nacional del Agua, 2018). From a geotechnical perspective, Mexico City has been broadly divided into three areas radiating away from the basin; the lake, transition, and hill zones. The city is prone to subsidence of up to 30 cm per year (Chaussard et al., 2014), increasing flood risk and necessitating round-the-clock water pumping to drain the city (Comisión Nacional del Agua, 2010; Delgado-Ramos, 2015). Rapid, often unplanned urban expansion occurred during from the 1950's to the 1980's, with continued formal and irregular development to the present day (Lerner et al., 2018). Based on the urban green areas inventory, the average green space surface per inhabitant in Mexico City is 7.54 m^2 (SEDEMA, 2020). Mexico City ranks in the bottom 10% of OECD (Organisation for Economic Cooperation and Development) for environment, and bottom 20% for safety, housing, health and income, with wide regional disparities (OECD, 2019).

3.1.2. The city of Bristol

Bristol is the 10th largest city in the United Kingdom, and one of ten 'core cities', with an estimate population of 464,400 (ONS, 2019). The city of Bristol has a temperate climate, broadly split in to four seasons: winter (December to February), spring (March to May), summer (June to August) and autumn (September to November). The city typically receives around 800 mm of rainfall annually. A total of 66% of land-use across the city is comprised of built up areas (buildings and impermeable surfaces), 31% green space and 3% water areas (Bristol Green Capital Partnership, 2015). The city saw rapid urbanisation between 1700 and the 1950's which led to fragmentation of green space, however, an estimated 88% of residents are within 300 m of a green space (Bristol Green Capital Partnership, 2015). In Bristol, 15% of residents reside in areas considered to be within the 10% most deprived areas in England and there are significant health and wellbeing inequalities within the city (BCC, 2019).

3.2. Study boundaries

Natural boundaries such as watersheds are increasingly being embedded into administration systems providing logical boundaries for the management of ecosystem processes (Bennett et al., 2010; Cohen & Davidson, 2011). Consequently, study boundaries were delineated in both Bristol and Mexico City using HydroBASINS (Lehner & Grill, 2013).

Hydrobasins are natural hydrological boundaries, that provide geographical information of sub-basin locations based on 12 different spatial scales (Level 12 is the smallest and Level 1 is the largest). To encompass the city of Bristol, HydroBASINS Level 10 data was most appropriate and three Level 10 HydroBASINs were merged to form the study boundary (3566 km^2; Fig. 1). For Mexico City, given the size of the wider conurbation HydroBASIN Level 8 data was selected. Use of the HydroBASINS contained 95.1% and 80.5% of the administrative footprints respectively for Bristol and Mexico City (notwithstanding that some city limits extend into the Bristol estuary). Whilst not covering the entire of Mexico City, the project boundary includes a representative socioeconomic gradient across the majority of Mexico City (3101 km^2; Fig. 1).

3.3. Social and economic gradients

3.3.1. Bristol

To obtain a socioeconomic gradient across the Bristol study area The Index of Multiple Deprivation (IMD) was used. The IMD is the official measure of relative deprivation in England, which provides combined scores, and national ranks and deciles based upon seven domains: income deprivation; employment deprivation; education, skills and training deprivation; health deprivation and disability; crime rate; access to housing and services and; living environment deprivation (Noble et al., 2019). The index ranks every area of England, termed Lower Super Output Areas (LSOA), which contain an average of ~1500 individuals, from 1 (most deprived) to 32,844 (least deprived) and enables the direct comparison of LSOA's in terms of relative deprivation. In all, 437 LSOAs were included in the Bristol case study, which are spread evenly across the range of IMD values, with only the least deprived 10% not represented (Fig. S1).

3.3.2. Mexico city

The Human Development Index (HDI) is a summary measure based upon a set of quality of life indicators: 1) the possibility of enjoying a long and healthy life, assessed by life expectancy at birth; 2) the ability to acquire formal education, measured by mean number of years of schooling for adults aged 25 years and more and; 3) the opportunity to have resources that allow a decent standard of living, determined by gross national income (GNI) per capita. The HDI uses the logarithm of income to reflect the diminishing importance of income with increasing GNI, and in Mexico City is fitted to municipality (Permanyer, 2013). The HDI is the geometric mean of normalized indices for each of the three dimensions. HDI data for the Mexico City project boundary enables site selection to work across the deprivation gradient (Fig. 1).

HDI is mapped to a combination of municipalities across Mexico and boroughs within Mexico City (16). Municipalities are the second-level administrative divisions of Mexico, where the first-level administrative division is the state. The autonomy of municipalities was recognised by constitutional reforms in 1983 (article 115) and 1999, and are governed by state constitution and legislation. The average surface area of the 47 municipalities and boroughs within the study area is 109 km^2 with an average population of 320878 (INEGI, 2015). HDI across the municipalities range from HDI 0.63 to 0.92 (mean 0.76) (Fig. S1), which corresponds to three (out of four) categories defined by UNDP in 2014, and retained for 2020.

3.4. Blue space digitisation

All mapping was undertaken using ESRI ArcMap v10.5.1 (ESRI, CA, USA). In Bristol, all surface water feature codes (such as rivers, static water and springs) were first extracted from the OS Mastermap layer to create a surface water layer (OS, 2019). Surface water features were verified using the OS Open Carto (OS OpenData) basemap and aerial photography tiles. Waterbodies that were clearly removed or lost to development, were removed from the surface water layer, and waterbodies not included in the Mastermap layer were added. For the case of Mexico, the most complete official source of blue spaces distribution is the national cartographic database Hydrology (1998) published by the National Commission on water (Comisión Nacional del Agua) and the

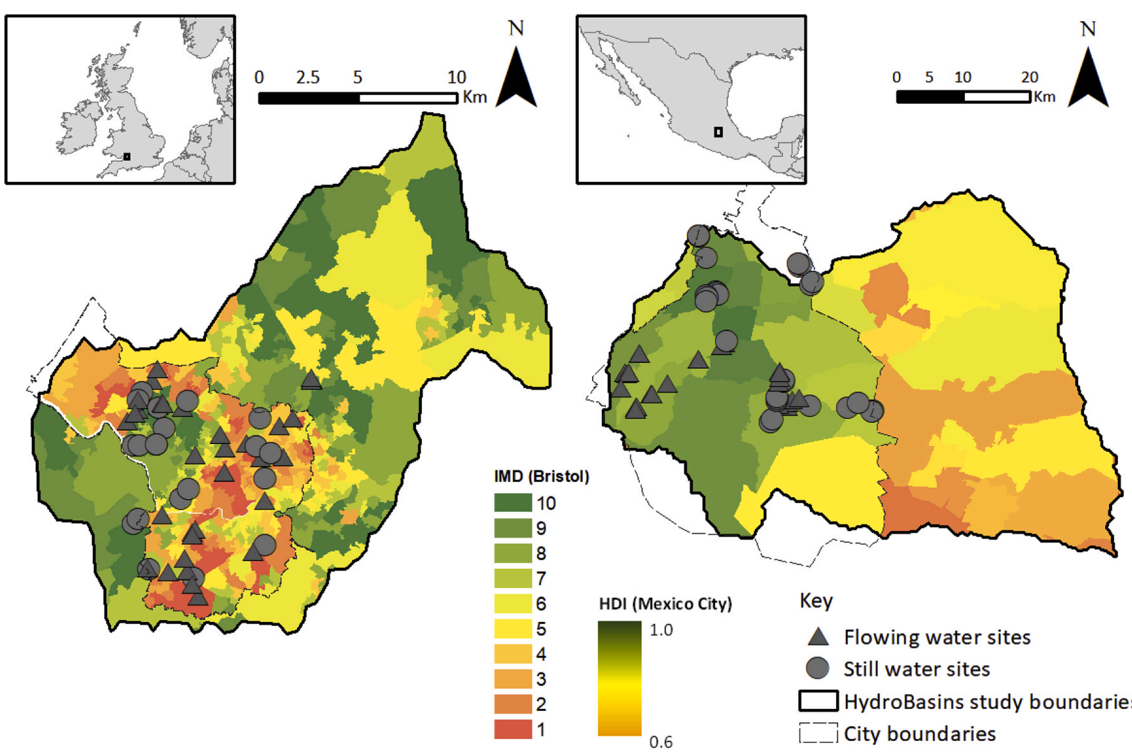

Fig. 1. Bristol and Mexico City study boundaries, rapid assessment site locations (flowing and still water) and socioeconomic gradients (IMD - Index of Multiple Deprivation deciles within Lower Super Output Areas (LSOAs), UK and HDI - Human Development Index within Municipalities, Mexico).

National Database on Hydrological micro watersheds published first in 1970 and reviewed in 1998. Both databases are available in 1:250000 scale. Due to a lack of a more updated and detailed database, all surface water features in Mexico City were digitised using a combination of OpenStreetMap (OpenStreetMap contributors, 2019), Google Earth imagery, and author's own knowledge while making reference to the official sources. Once all surface waters in Bristol and Mexico City were digitised, surface areas were calculated and all features were assigned to one of the following categories: canal, drain (i.e. ditches), fountain, lake (>20,000 m^2), pond (<20,000 m^2), reservoir (or dam), rivers and streams, spring, tidal water or well (see Tables S1 and S2). Lagoons were unique to Mexico City. In addition, two broader categories were created, 'flowing' and 'still water', reflecting the hydrology of the freshwater habitats. Further adjustments (e.g. if a water body did not exist or belonged in a different category) were made to the GIS data following the rapid assessment process (i.e. walkover surveys).

In Bristol, blue space coverages were split by LSOA parcel ($n = 437$) and joined to IMD data, resulting in a database containing all water bodies and deprivation data assigned to each LSOA within the project boundary. Where LSOAs were intersected by the project boundary, a correction was incorporated to account for the proportion of the LSOA within the project boundary. In Mexico City, blue spaces were split by Municipality using the same procedure as for Bristol LSOAs ($n = 47$).

3.5. Rapid assessment of local, site-scale social and ecological factors

A rapid assessment tool was developed to record observable factors at a site-scale (using Survey123 for ArcGIS) software which could be accessed through a smartphone or tablet (see Appendix 1 for full guidance). Data was collected by the investigatory team and student volunteers following a training event across a range of social and ecological factors at 54 sites in Bristol, and 60 sites in Mexico City, that were visited on average (median) three times and once each in the two study areas respectively. All site visits were carried out between 08:00 and 17:00, between August 2019 and February 2020 (Fig. 1).

Variables measured included the presence of invasive non-native species (INNS) and vegetation structure (absent, <25%, 25–50%, 50–75%, >75%) within the riparian zone (extending 15 m landward, 7.5 m up- and down-stream, adapted from the Lake Habitat Survey; (Rowan et al., 2006). The presence of 12 vegetation types (Rowan et al., 2006), water colour, discharges and visual pollution (litter, oily sheen, foam, adapted from the FreshWater Watch methodology; Thornhill et al., 2018), were measured from the littoral zone. A range of factors were also recorded that related to the amenity value and access of the site; odour (1–10), noise (decibel; Radicchi, 2017), 12 amenity uses (e.g. footpaths, dog walking), access (open, private, timed) and 13 accessibility factors derived from Sensory Trust and Countryside Agency outdoor access guidance (The Countryside Agency, 2005; Sensory Trust, 2017). From these observations 12 rapid assessment metrics were calculated in relation to vegetation and habitat complexity, observable impacts, amenity and access (Table 1).

3.6. Statistical analysis

All statistical analysis was undertaken in the R environment (R Core Team, 2019). The percentage of blue space per m^2 of land cover, and per person of land cover (%m^2/person) was calculated by i) extracting the total area of blue space (and sub-categories) within each LSOA (Bristol) or municipality (Mexico City), ii) expressing this as percentage coverage within each LSOA or municipality, and iii) dividing this percentage by the population. Where LSOAs or municipalities were clipped at the study boundary, this value was calculated proportional to the unclipped area. Populations within Mexican municipalities were extracted from the 2015 Intercensal Survey (INEGI, 2015).

Spearman's Rank correlations were calculated between socioeconomic metrics (IMD, HDI and their components) and blue space categories to assess for covariance and broad trends at a regional, city-scale at a 1% significance level ($p < 0.01$). One from any two blue space or socioeconomic variables with a correlation of $\rho \geq 0.8$ were retained, whilst rarely occurring blue space categories (<25% incidence across LSOAs or municipalities) were removed to retain statistical power. Once blue space coverages were binned into quartiles to account for highly uneven distributions, Kruskal-Wallis tests were undertaken to assess for any significant differences in socioeconomic metrics across blue space quartiles with a post-hoc Nemenyi test to ascertain which groups were significantly different.

An unconstrained ordination (principal component analysis; PCA) was employed to explore associations between environmental, access

Table 1
Description of metrics derived from a rapid assessment of local environmental, access and amenity observations.

Metric	Description	Calculation	Range	Study range
INNS presence	Presence or absence of invasive non-native species	Presence of a single INNS on any visit	0–1	0–1
Riparian diversity	Diversity of habitats within the riparian zone (15m × 15m plot)	Count of different habitat types within riparian zone	0–8	0–8
Riparian productivity	Proxy of biomass within the riparian zone	Sum of approximate coverages based on an ordinal scale (1–4) of 6 vegetation classes in the riparian zone	0–24	0–19
Instream diversity	Diversity of vegetation types within the littoral zone (15m x instream 10m plot)	Count of different vegetation types within the littoral zone	0–8	0–6
Instream complexity	Diversity of mesohabitats within the littoral zone	Count of different mesohabitats within the littoral zone	0–9	0–12
Water colour	Evidence of discolouration to the water column	Presence of green, brown, yellow or other colouration on any visit	0–1	0–1
Discharges	Presence of discharges (e.g. land drainage), estimated to be from industry, impermeable surface drainage or residential	Count of different possible discharges recorded across visits	0–3	0–3
Visual pollution	Presence of visual pollution (litter, foam or oily sheen)	Count of different source of visual pollution across visits	0–3	0–3
Odour	Subjective assessment of odour during visit	Average of categorical measure between 1 and 10	1–10	1–8
Noise	Level of ambient noise (natural or artificial) during site visit	Average decibel reading during 30s using HushCity app.	0 - ∞	21.2–77.2
Amenity	Use of site for amenity e.g. recreation	Count of different amenity uses and facilities observed at the site (footpaths, dog walking, car parking, benches, interpretation boards, cycling, children's play, bird feeding, fishing, boating, other	0 - ∞	0–8
Access for all	Accessibility of site when assessed against recommendations of The Sensory Trust	Composite metric calculated: disabled parking (+1), use of textured surfaces (±1), path of loose materials (±1), ramps and/or handrails where steep (±2), wide paths (2m, (±0.5), non-slip surfaces provided (±0.5), high steps (>150 mm, ±1)	−5.5–6.0	−5.5–2.4

and amenity factors. The PCA was carried out using the 'FactoMineR' (Lê et al., 2008) and 'factoextra' (Kassambara & Mundt, 2020) packages. Data was standardized prior to the PCA to account for different measurement scales (0 ± 1 SD). Eigenvalues and variance explained were extracted for those axes capturing at least 10% of variation (4). Finally, PCA coordinates were extracted for the first two axes to generate two combined social-ecological metrics for each site. The 12 rapid assessment metrics and two social-ecological metrics (based on the first two PCA axes) were tested for any spatial associations with socioeconomic metrics as delineated by IMD deciles (Bristol) and the HDI (Mexico City) using Spearman's Rank correlations ($P < 0.01$), followed by a simple linear regression in base R (R Core Team, 2019) to test for the amount of variance explained.

4. Results

4.1. Blue space availability

The composition of blue space in Bristol and Mexico City contrasted markedly (Table 2). By surface area, flowing water sources were more prevalent in Bristol (0.86% $LSOA^{-1}$) compared to still water sources (0.39% $LSOA^{-1}$), whereas still water sources were more prevalent in Mexico City (0.89% $municipality^{-1}$) than flowing (0.48% $municipality^{-1}$). Furthermore, the flowing water sites in Mexico City which are mountainous in origin change their flow between the wet and dry seasons, such that these figures may be an overestimate during drier periods. Overall, the total area of blue space was lower in Bristol (829 ha) than in Mexico City (4835 ha). However, the percent of blue space per Municipality and LSOA was lower in Mexico City (1.4%) than in Bristol (2.2%).

Of the water body categories, Bristol has few canals (1.16 ha), restricted to the Kennet and Avon Canal. The average density of ponds within the study area is relatively high (10.1/km^2), however, these are largely located northeast of the city. Discrete, small water bodies such as ponds are uncommon across Mexico City, with just 112ha (0.04/km2) estimated within the study boundary. However, shallow wetlands (natural and artificial) are more frequently recorded in Mexico City and account for 0.93% of the study area (111ha). The presence of tidal waterways is a novel category within the Bristol study area, and accounts for 2.8% of blue space within the study boundary.

Relative to the population, residents of Bristol city have approximately double the quantity of blue space per individual (0.0015% m^2/person) than those living Mexico City (0.0007% m^2/person), notwithstanding the water body type. Any relative increase in water body type in Mexico City compared to Bristol (e.g. more than twice the amount of still water), is offset by Bristol's high population density.

4.2. Associations between blue space availability and socioeconomic indices

After removal of covariables between blue space categories (see Figs. S2 and S3) and low-incidence categories (Table 2), those retained in both Bristol and Mexico City were flowing water, still water and drains. Socioeconomic metrics retained in Bristol differ in number and category from Mexico City. The four metrics retained in Bristol were: IMD, crime, access to housing and services and local environmental quality; and three in Mexico City: expected years of schooling (AESESC), income and HDI. Thus 7 and 6 social metrics and blue space categories variables were retained in Bristol and Mexico City respectively.

Statistically significant differences (Kruskal-Wallis post hoc Nemenyi, $P < 0.05$) were identified in both Bristol and Mexico City in relation to the availability of still waters, where a greater availability of still waters corresponded to lower levels of deprivation in Bristol (Fig. 2a) and to higher levels of income in Mexico City (Fig. 3a). The presence of flowing water was associated with lower levels of income in Mexico City, and a lower HDI rating (Fig. 3b and c). Ditches and drains, a subset of flowing water, were indicative of a higher quality of local environment in Bristol (Fig. 2b).

4.2.1. Local-scale associations between environmental quality, access and amenity

A PCA of local scale metrics derived from a rapid assessment explained 67% and 66% of variation of the first four dimensions in Bristol (Table 3) and Mexico City (Table 4) respectively (see also Fig. S4). In Bristol, the first dimension accounted for 25% of explained variance, and described a gradient from complex habitats, to those that received discharges and were more odorous. The second dimension accounted for 18% of explained variance, and described a gradient from diverse riparian habitat structure, to more noisy habitats (higher decibel rating).

In Mexico City, the first dimension, which also accounted for 25% of explained variance, described a gradient from more complex habitats to those that were noisier, odorous and had coloured water. The first dimension also highlighted that blue space was more accessible to all, but held lower levels of amenity use. The second dimension, which accounted for 19% of explained variance, described a gradient from highly coloured waters which supported invasive non-native species, to those with productive and structurally diverse riparian habitats.

4.2.2. Local-scale environmental quality, access and amenity across socioeconomic gradients

Few strong associations were found between local-scale metrics, and socioeconomic gradients at a city-scale in either Bristol or Mexico City (Figs. S5 and S6). The strongest of these associations was found between housing accessibility and the first dimension of the PCA of local scale metrics in Bristol (Adj R^2 0.10 $P = 0.01$), suggesting that as housing becomes more accessible, local blue spaces have less complex habitats,

Table 2
Blue space summary statistics for Bristol and Mexico City study areas. Asterisks indicate low-incidence categories, occurring in less than 25% of Lower Super Output Areas (LSOA, Bristol) or Municipalities (Mexico City).

	Bristol (n = 437)			Mexico City (n = 47)		
	Total area (ha)	%LSOA ±1SD (min. - max.)	%m^2/person ±1SD	Total area (ha)	%Municipality ±1SD (min. - max.)	%m^2/person ±1SD
Blue space	828.5	2.18 ± 7.2 (0.0–100)	1.5^{-3}±4.8^{-3}	4834.8	1.37 ± 2.9 (0.0–18.0)	7.2^{-4}±2.3^{-3}
Flowing	340.6	0.90 ± 5.5 (0.0–100)	6.0^{-4}±3.5^{-3}	2126.1	0.48 ± 0.4 (0.0–2.1)	6.6^{-4}±2.3^{-3}
Rivers and streams	178.4	0.41 ± 1.6 (0.0–23.9)	2.7^{-4}±1.1^{-3}	1730.1	0.39 ± 0.3 (0.0–1.0)	6.1^{-4}±2.3^{-3}
Ditches and drains	94.3	0.09 ± 0.29 (0.0–3.9)	6.3^{-5}±1.9^{4}	131.2	0.04 ± 0.2 (0.0–0.9)	5.2^{-5}±3.5^{-4}
Canals	67.8	0.40 ± 0.53 (0.0–100)*	2.6^{-4}±3.5^{-3}	264.7	0.05 ± 0.2 (0.0–1.6)*	1.1^{-7}±5.5^{-7}
Still	319.3	0.36 ± 1.92 (0.0–29.6)	2.4^{-4}±1.2^{-3}	2707.3	0.89 ± 2.9 (0.0–18.0)	5.9^{-5}±3.9^{-4}
Reservoirs	23.2	0.05 ± 1.02 (0.0–21.3)*	3.3^{-5}±6.8^{-4}	55.3	0.01 ± 0.1 (0.0–0.2)*	1.2^{-7}±7.1^{-7}
Lakes	10.9	0.07 ± 0.84 (0.0–15.7)*	4.6^{-5}±5.6^{-4}	2482.5	0.84 ± 2.9 (0.0–18.0)	5.9^{-5}±3.9^{-4}
Ponds	186.7	0.24 ± 1.02 (0.0–16.2)	1.6^{-3}±6.8^{-3}	50.6	0.02 ± 0.0 (0.0–0.1)	8.8^{-8}±2.2^{-7}
Other	0.51	0.62 ± 3.5 (0.0–40.9)*	4.2^{-4}±2.3^{-3}	111.9	0.02 ± 0.1 (0.0–0.4)*	5.1^{-8}±1.7^{-7}

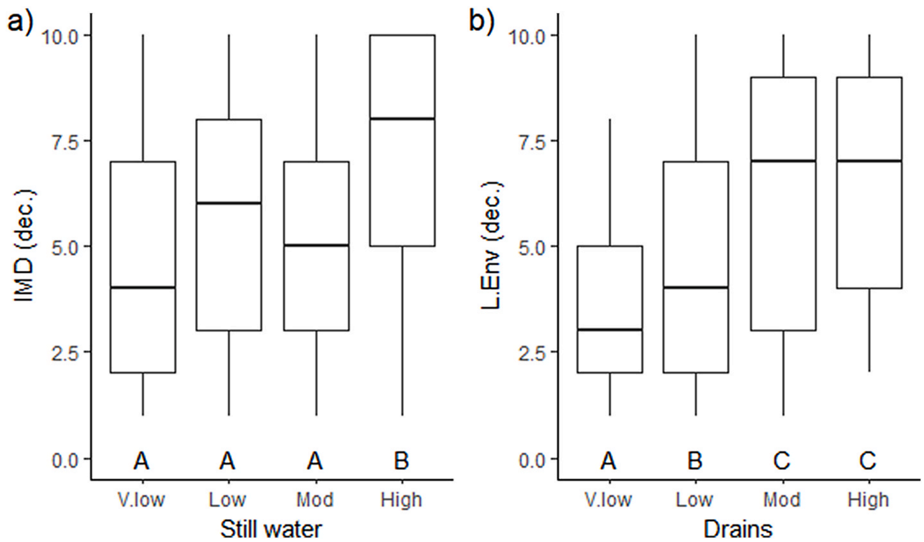

Fig. 2. Socioeconomic and blue space correlations in Bristol, after removing covarying factors (ρ ≥ 0.8). Only variables with significant correlations (Spearman's, P < 0.01, Fig. S2) are presented. Still water and drain availability split into four classes of equal membership from very low availability to high. Lettering denotes significant differences between classes (Kruskal-Wallis, post-hoc Nemenyi, P < 0.05). Boxes represent inter-quartile range, whiskers identify minimum and maximum values.

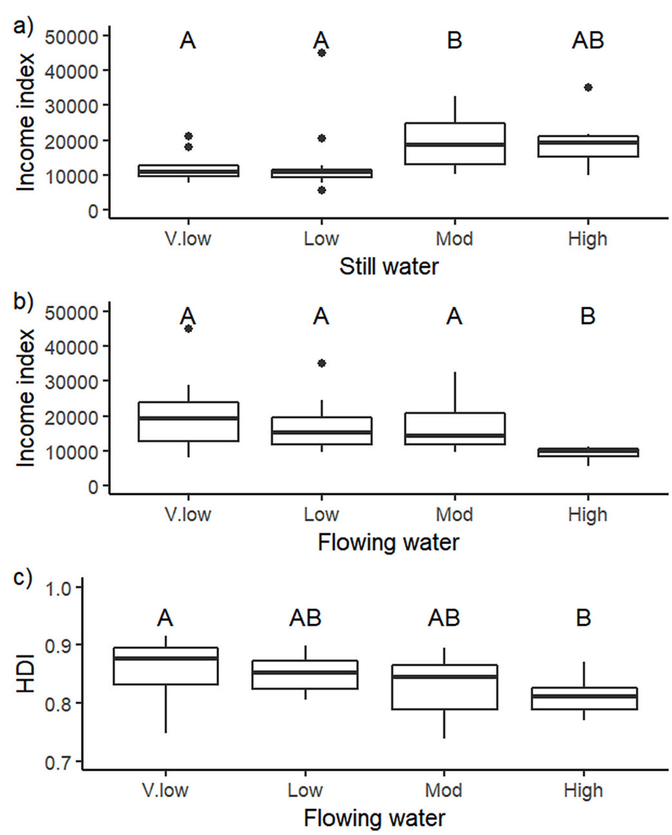

Fig. 3. Socioeconomic and blue space correlations in Mexico City, after removing covarying factors (ρ ≥ 0.8). Only variables with significant correlations (Spearman's, P < 0.01, Appendix 2) are presented. Still water and drain availability split into four classes of equal membership. Lettering denotes significant differences between classes (Kruskal-Wallis, post-hoc Nemenyi, P < 0.05). Boxes represent inter-quartile range, whiskers identify minimum and maximum values.

and are more likely to be odorous, and to receive urban discharges (Fig. 4 and Fig. S6).

The diversity of vegetation within the wetted perimeter had a statistically significant correlation with several of the socioeconomic metrics in Mexico City (Figs. S6 and S8), with more diverse habitats associated with lower socioeconomic status, for example an overall lower HDI score (Adj. R^2 0.15 P < 0.01). However, the observed structural diversity of the freshwater vegetation visited in Mexico was very low (mean 0.79).

5. Discussion

Despite the importance of urban blue space for society and wildlife, these spaces have been poorly considered compared to urban green space (Cole et al., 2019; Garcia-Lamarca et al., 2021). In this study, several associations between environmental quality and socioeconomic factors were identified, which could have important implications for how blue spaces are considered and managed in the future in urban areas. Given the increasing urban land coverage and urban population globally, and the importance of blue space for society (particularly wellbeing), understanding the relationship between urban freshwater quality and access to urban blue space for citizens has important implications for freshwater management and future urban resilience (Hill et al., 2021).

The findings revealed that still water availability was indicative of higher socioeconomic status in both case studies, but contrasting city evolutions generated some contrasts. At a local scale, environmental gradients from more complex to disturbed habitats were observed, as well as potential wellbeing and amenity benefits that could be derived from complex and productive riparian habitats (e.g. reducing noise). Evidence also emerged that blue space was unevenly distributed across socioeconomic gradients, and that environmental quality may exacerbate inequalities and risk increasing ecosystem disservices.

Given the (1) increasing population and development pressures on social and ecological systems (e.g., Reid et al., 2019) and (2) the importance of blue space for ecology and society, understanding the distribution and access to urban blue space for citizens, and their contribution to increasing social-ecological resilience in urban space is highly relevant. These spaces are commonly considered a subcategory under the umbrella of greenspaces (Haeffner et al., 2017), and there has been little systematic assessment of the availability of surface waters in urban areas, especially in low-mid income regions (Labib et al., 2020). In the present study, a parallel analysis was undertaken in Bristol, UK and Mexico City, Mexico, two contrasting cities that differ considerably in their economic, political, social and environmental contexts, and two participants in the 100 Resilient Cities project (Rockefeller Foundation, 2020). Here we assessed (i) whether blue space availability was indicative of socioeconomic status at a regional (catchment) scale, (ii) covariance between ecological and social (amenity) characteristics at a local, site-scale, and (iii) patterns between local social-ecological factors

Table 3
Eigenvalues from successive extractions of principal components from 14 social and ecological metrics derived from a site-scale rapid assessment at 54 sites in Bristol, UK (see also Appendix 3).

Dim.	Eigen.	% var.	% cum	InvasivesP	RiparianDiv	RiparianProd	VegDiv	HabComplexity	Colour	Discharges	VisualPollution	Odour	Noise	Amenity	Access4All
1	2.72	24.7	24.7	NS	NS	NS	NS	−0.79	NS	0.53	0.48	0.77	NS	NS	NS
2	1.92	17.5	42.2	NS	0.80	0.83	NS	0.39	NS	0.45	0.30	NS	−0.30	NS	NS
3	1.59	14.5	56.7	NS	NS	NS	NS	NS	0.74	NS	0.27	NS	0.36	0.58	0.65
4	1.13	10.3	67.0	NS	NS	0.29	NS	NS	NS	−0.33	NS	NS	0.72	NS	−0.44

InvasivesP – Presence of any INNS, RiparianDiv – Structural diversity of the riparian zone, RiparianProd – Proxy for biomass in the riparian zone, VegDiv – Structural diversity of the littoral zone, HabComplexity – Diversity of mesohabitats in the littoral zone, Colour – Water colour (any), Discharges – Presence of any discharges, VisualPollution - Number of different visual pollutants seen, Odour – Odour, Noise – Level of noise (decibels), Amenity – Count of different amenity uses, Access4All – Score according to disabled access. See also Table 1.

Table 4
Eigenvalues from successive extractions of principal components from 14 social and ecological metrics derived from a site-scale rapid assessment at 60 sites in Mexico City, Mexico (see also Appendix 3).

Dim.	Eigen.	% var.	% cum	InvasivesP	RiparianDiv	RiparianProd	VegDiv	HabComplexity	Colour	Discharges	VisualPollution	Odour	Noise	Amenity	Access4All
1	3.01	25.1	25.1	NS	NS	NS	−0.60	−0.55	0.46	0.63	0.43	0.67	0.66	−0.42	0.65
2	2.31	19.2	44.3	−0.70	0.84	0.75	NS	0.31	−0.45	NS	NS	NS	0.28	NS	NS
3	1.49	12.4	56.8	NS	NS	NS	0.48	0.64	−0.26	0.49	0.53	0.33	NS	NS	NS
4	1.15	9.6	66.3	0.40	NS	0.46	0.33	NS	NS	NS	NS	0.34	NS	0.65	NS

InvasivesP – Presence of any INNS, RiparianDiv – Structural diversity of the riparian zone, RiparianProd – Proxy for biomass in the riparian zone, VegDiv – Structural diversity of the littoral zone, HabComplexity – Diversity of mesohabitats in the littoral zone, Colour – Water colour (any), Discharges – Presence of any discharges, VisualPollution - Number of different visual pollutants seen, Odour – Odour, Noise – Level of noise (decibels), Amenity – Count of different amenity uses, Access4All – Score according to disabled access. See also Table 1.

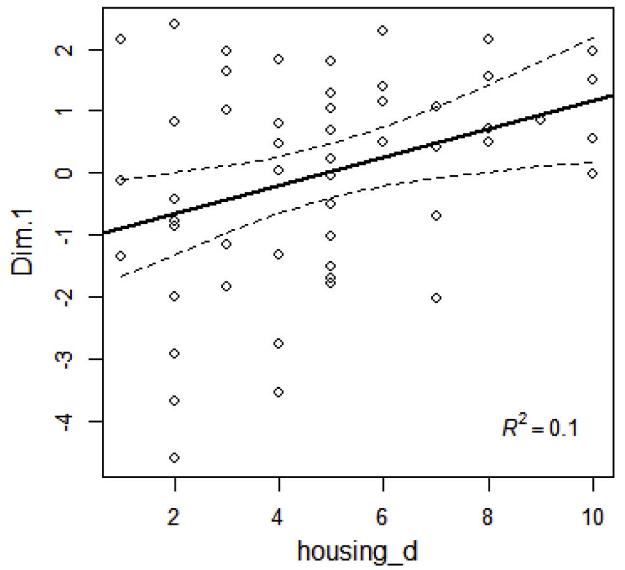

Fig. 4. Correlation between regional, city-scale socioeconomic metric housing_d (barriers to housing and services) and local, rapid assessment metric PCA Dim. 1 (complex habitats, to those that received discharges and were more odorous) in Bristol, where adjusted R^2 values are reported for linear regression ($P < 0.01$).

and regional socioeconomic status.

5.1. Catchment associations between blue space availability and socioeconomic indices

We found an association between the coverage of still waters specifically, and indicators of higher socioeconomic status (IMD or income, and their covariables) in both case studies. The availability and use of blue space by urban populations with higher socioeconomic status has been previously identified (Haeffner et al., 2017; Sander & Zhao, 2015; Wendel et al., 2011), and for green space in Mexico City (Fernández-Álvarez, 2017). Several studies have identified the capitalization of water in real estate prices (Bourassa et al., 2004; Sander & Zhao, 2015), which may be particularly relevant for still waters, as these urban ecosystems are almost entirely artificial products, often constructed for flood alleviation and amenity purposes in new developments (Gledhill & James, 2012; Thornhill et al., 2017).

For flowing water, a contrasting pattern was recorded with a greater coverage of flowing waters associated with lower socioeconomic status in Mexico City and no discernible pattern in Bristol. The different associations between socioeconomic status and blue spaces may be an artefact of the contrasting urban form of the two cities in a similar way that the anticipated positive correlations between high socioeconomic status and species diversity have been confounded elsewhere (Kuras et al., 2020). In Mexico City, people migrate towards the city centre to seek higher income employment (Ezcurra & Mazari-Hiriart, 1996), and therefore into the lake basin zone (more still water; Fig. S9), compared to lower income households in the rural and peri-urban regions in the transitional and hill zones with more flowing water (Fig. S10). By contrast, residents of high income economies (e.g. UK) may proactively migrate to more rural regions with increasing wealth (King, 2012), or to areas with more green and blue space (e.g. waterfront apartments) (Sander & Zhao, 2015), thus bringing them in closer proximity to city parks and gardens and their associated blue spaces.

The prevalence of drains and ditches in the Bristol study indicated better local environmental quality. Drainage features are strongly associated with rural or peri-urban environments and the improved local environmental quality likely reflects improvements in air quality along the urban rural environment (McDonnell et al., 1997), to which the living environment IMD indicator responds. Furthermore, multiple European studies have highlighted the potential for drains and ditches to support high levels of biodiversity (Verdonschot et al., 2011; Hill, Chadd, et al., 2016).

5.2. Local associations between environmental quality, access and amenity

The rapid assessment protocol identified similar gradients in local environmental quality in both case studies, from more structurally complex habitats, to those more degraded. In Bristol, a negative association of urban discharges, and odour with environmental quality supports studies regarding the importance of reducing discharges (particularly residential) in controlling stream nutrient concentrations (Álvarez-Cabria et al., 2016; Loiselle et al., 2016), which can typically lead to habitat degradation and increased biotic and environmental homogeneity (Walsh et al., 2005; Wenger et al., 2009). Furthermore, the presence of discharges and associated odours are likely to render a blue space less appealing to prospective visitors, or nearby residents (Sado-Inamura & Fukushi, 2018).

More complex and productive riparian habitats were both associated with reduced noise levels. Higher levels of unwanted sound (e.g. transport) is increasingly acknowledged to contribute to higher levels of social anxiety (Stansfeld et al., 2000) and that more natural sounds are preferred over artificial (Irvine et al., 2009). Although we did not discern between artificial and natural sounds, higher noise levels were largely linked to the intensity of urbanisation nearby (e.g. motorised transport and construction). Such noisy environments offer fewer health and wellbeing benefits, a factor that components of riparian habitats (i.e. trees, shrubs), are well known to mitigate (Herrington, 1974). For complex riparian habitats to develop, less intense land cover is required in the catchment (e.g. von Behren et al., 2013) and for riparian width to be increased (Ives et al., 2011).

Other amenity and environmental quality associations were however more nuanced in Mexico City. Those blue spaces that were typically more accessible to people with disabilities (access for all), were also more degraded (noisy, odorous and with coloured water) with simple habitat structures, and had fewer amenity uses. This may indicate elements of environmental injustice, whereby disabled users may be restricted to visiting poorer quality spaces with fewer health and wellbeing benefits (Burns et al., 2009). Similarly, it may indicate the potentially conflicting challenge of managing more sensitive habitats that are prone to disturbance while also promoting public access (Alvey, 2006).

5.3. Local environmental quality, access and amenity across regional socioeconomic gradients

Few robust associations could be made between locally derived metrics and socioeconomic gradients, which was likely due to the low number of replicates and the relative low spatial distribution of sampled sites across the two study areas (Fig. 1). Indeed, particularly for more dynamic and changeable variables such as odour, noise and water colour we recommend their measurement on at least a quarterly or seasonal basis to represent the typical or chronic situation, while acute and stochastic issues would require targeted monitoring.

In Bristol however, less complex habitats were associated with areas with more barriers to housing and services. This suggests that residents with lower socioeconomic status had local access to blue spaces that were more often of a lower environmental quality. Thus, not only were fewer blue spaces available (still waters), that they were more likely to offer disservices such as odour and increased stress (Lõhmus & Balbus, 2015; Pitt, 2018). This further highlights the need to not only consider distribution, but environmental quality (Baró et al., 2019); which our rapid assessment approach facilitated. This result also supports the literature emphasising the inequities embedded in urban development and access to high quality blue space (Shokry et al., 2020).

In Mexico City, more diverse habitats tended to be associated with lower socioeconomic status. This may reflect the historical development of Mexico City, where informal settlements of low-income populations were built in the second half of the 20th Century in areas designated for ecological conservation (Aguilar & Santos, 2011), or the simplified nature of some aquatic habitats (e.g. urban streams; Meyer et al., 2005; Walsh et al., 2005) where residents of higher socio-economic status were located. However, this finding needs to be treated with caution as the observed diversity of habitat was very low (maximum of two types of vegetation structure), and more sensitive metrics are likely to be required.

In conclusion, future urban planning should incorporate not only high quality green, but also blue spaces to promote the health and wellbeing of a city's population. In addition, by increasing accessibility to high quality blue spaces the observed bias of social inequality associated with blue spaces, could be mitigated. We found that still waters may be a simple and effective indicator of socioeconomic wealth. Urban form is an important consideration when evaluating patterns in blue space distribution yet findings may or may not be generalizable (Haeffner et al., 2017), and the contrasting findings for Bristol and Mexico City encourages further research to develop equally obtainable, but more sensitive social and ecological metrics for urban environments. Indeed, few socioeconomic datasets are available for Mexico City that adequately captures the variability in socioeconomic status across the city. More preferable, would be the development of indicators at a spatial scale comparable to the UK e.g. Área Geoestadistica Básica (AGEB); more closely comparable to the LSOAs and approximately 1500 individuals.

Although distribution of blue space is a key consideration, a robust rapid assessment process developed for this study can help reveal important trends associating socioeconomic status, amenity use and access with environmental quality. The development of the rapid assessment begins to respond to recent calls for tools that allow for comparable assessments of environmental aspects and attributes of urban blue spaces for health and wellbeing (Mishra et al., 2020). The rapid assessment tool has considerable potential to tackle urban ecological or environmental degradation and community access to blue spaces.

The rapid assessment is an easy to use tool that can generate geographically specific data, allowing for the identification of specific locations in need of management interventions and also the identification of high quality areas for conservation. Through the application of this tool more widely, there may be opportunities to increase the environmental quality of urban blue spaces, and the local communities' enjoyment of blue space through increased access to high quality sites.

Author statement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2022.102716.

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