Contribution of urban green infrastructure as part of a vulnerability and risk assessment to environmental stressors

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Research question

How are the ecosystem services provided by the urban green infrastructure helping to mitigate the vulnerability and risk to environmental stressors in cities?

Objectives

General

Analyze the role that certain ecosystem services delivered by the green infrastructure in Bogotá have to reduce city dweller´s vulnerability and risk to urban stressors such as flooding, air pollution and low access to recreational areas.

Specific

1. Evaluate ecosystem services provided by the urban forest (i.e. rainfall interception and PM2.5 removal) and green areas (i.e. recreation potential) as well as its distribution between human groups that live in contrasting socioeconomic contexts.
2. Determine how different stakeholders prioritize ecosystem services that may contribute to reduce the vulnerability and risk to environmental stressors.
3. Describe and analyze the relation between tree cover, access to green areas and socioeconomic strata, with the vulnerability and risk to urban stressors.
4. Develop cost-benefit analyses of implementing urban forestry as a measure to reduce risk and vulnerability.

1. Introduction

In recent decades, the world's population has moved at an accelerated pace to urban centers. In Latin America, 89% of the population is expected to be concentrated in urban areas by 2030 (United Nations 2015). Even though cities have promoted economic growth and wellbeing, high levels of massive consume, densification, and transformation of the urban and peri-urban territory, have led city dwellers to be exposed to different urban stressors such as air pollution, floods, urban island effect, among others (UNEP 2007).

The exposure of people to the effects and hazards derived from the urban centers' environmental degradation, along with city dweller's vulnerability, put them at risk (UNEP 2007). Vulnerability is especially critical in developing countries' megacities, where large socioeconomic gaps and alarming poverty levels force people to live in informal settlements, frequently located in marginal areas with poor access to natural resources (Inostroza 2017).

The ecological urban planning framework addresses the challenge of maintaining human wellbeing in urban developing areas in communion with environmental integrity by settling urban development on the biodiversity and its ecosystem services (ES). This urban planning focus promotes the conservation and sustainable use of the 'ordinary biodiversity' such as common species of urban trees, and garden flora that are all part of the urban green infrastructure (Andrade, Remolina, and Wiesner 2013). Green Infrastructure (GI) is defined as the interconnected network of green spaces that maintain the functions and values of the natural ecosystems and their capacity to provide ES (Ahern 2007; Benedict and MacMahon 2006). GI is one of the main ecological urban planning strategies addressing vulnerability to urban stressors by increasing resilience and adaptive response (Ahern 2012; Meerow and Newell 2017). The application of the urban planning ecological framework is crucial as it provides understanding of cities as socio-ecological systems (Heymans et al. 2019; Andrade, Remolina, and Wiesner 2013).

Urban forests are considered one of the most important elements of the GI, since trees have a great potential to achieve multiple ecological and environmental functions that increase human wellbeing (Dobbs et al., 2018). Nowak et al. (2013) found that PM 2.5 removed by trees could reduce human mortality up to 7.6 people per year. Zabret and Sraj (2015) found that urban trees can reduce considerable the amount of runoff due to rainfall interception, which helps prevents floods.

In the last years, multiple studies in Latin America have focused on estimating and mapping the distribution of various ES provided by different green infrastructure elements at a city scale (Arroyave Maya et al. 2018; Dobbs et al. 2018; Escobedo et al. 2015; Escobedo and Nowak 2009). However, there are still gaps in knowledge on how the provision of ES can help mitigate the vulnerability and risk that people have to urban stressors. Despite it is known that ES provision increases the response capacity of public GI, it is uncertain in what degree these ES may reduce the vulnerability and risk of city dwellers considering their socioeconomic context.

Escobedo et al (2015) found that localities with higher incomes in Bogotá, have a greater provision of several ES (i.e. air pollution removal and higher real estate prices), as well as more diverse urban forests with a better structure. These findings exemplify the potential of the urban forest to provide ES, but also the inequity in the spatial distribution and access to these environmental benefits (Dobbs et al. 2018). Bogotá's ecological main structure, which includes the natural and semi-natural elements of the urban landscape, is considered the mainstay of the city's environmental services (POT, 2011). The consolidation of the ecological main structure in the territorial ordering of the city has helped strengthening public policies since 2002, reflected in an increase of ES provision, and in the connectivity of the areas that provide them (Dobbs et al. 2018).

The objective of this study is to assess the vulnerability and risk to three urban stressors that are relevant for Bogotá (i.e. floods, air pollution and low access to public recreational areas). We propose the use of an index-based approach that uses urban forest and green areas ES provision as indicators of response capacity, which contribute to the mitigation of the vulnerability and risk (FUNDASAL, 2020; MADS, 2018). To address floods, air pollution, and low access to green recreational areas, rainfall interception, $PM_{2.5}$ removal, and potential recreation were respectively assessed. The study also accounts for the way that different stakeholders prioritize between these environmental benefits, to analyze how vulnerability and risk can vary according to each stakeholder's needs and preferences. Results are expected to support public policies that promote ES and biodiversity as fundamental criteria for urban planning and for the reduction of socio-environmental gaps.

2. Materials and methods

2.1 Study area

Bogotá, Colombia is located at 2,600 m.a.s.l. and has a neotropical highland climate, with a mean temperature of 14.5 °C and an annual precipitation between 600 and 1200 mm (Instituto de Hidrología, 2006). The urban area has an extension of 380 km^2 and a population of approximately 7.8 million inhabitants (DANE, 2018). The administration is organized in 19 localities subdivided into 1085 neighborhoods (Fig. 1). For each block, the city has a socioeconomic stratification of six levels, that helps manage the charge for the public services (González et al. 2007). Low strata (1-2) are associated with low-income households while high socioeconomic strata (5-6) are related to wealthier neighborhoods.

The environmental ordering of the city is established around the ecological main structure, composed of protected areas, urban forests, river rounds, wetlands and large parks, which are all essential for the ecosystem balance of the territory (Andrade, Remolina, and Wiesner 2013). Other green areas such as gardens, street trees, green walkways and small parks, complement and help connect the elements of the ecological main structure (Quenguan, Bernal, and Barón 2017).

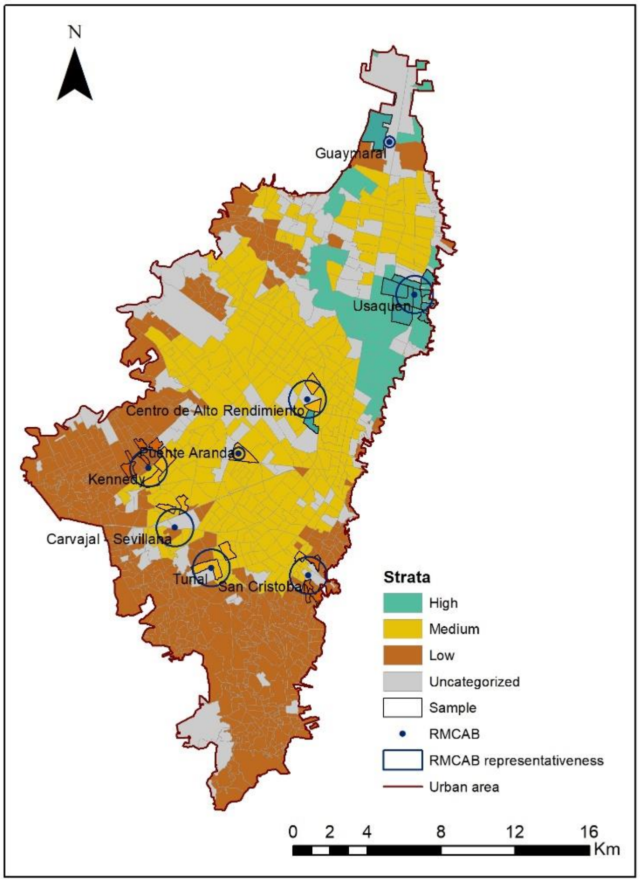

Fig. 1. Socioeconomic stratification of Bogota's urban area at a neighborhood scale. The figure includes the sampled neighborhoods based on the socioeconomic strata and the spatial representativeness of the stations of the air quality monitoring network of Bogotá (RMCAB).

2.2 Ecosystem services

Three ecosystem services were evaluated given their relevance in the context of Bogotá and the capacity of urban green infrastructure to address or mitigate floods, air pollution and low access to green recreation areas (Meerow and Newell 2017). Rainfall interception and air pollution removal were evaluated as the potential of the urban forest canopy to intercept rainfall and remove $PM_{2.5}$ respectively. Recreation potential was evaluated based on the green recreational areas with public access. Fig. 2 shows the spatial distribution of the elements of the urban GI in which the evaluation of the ES were based on.

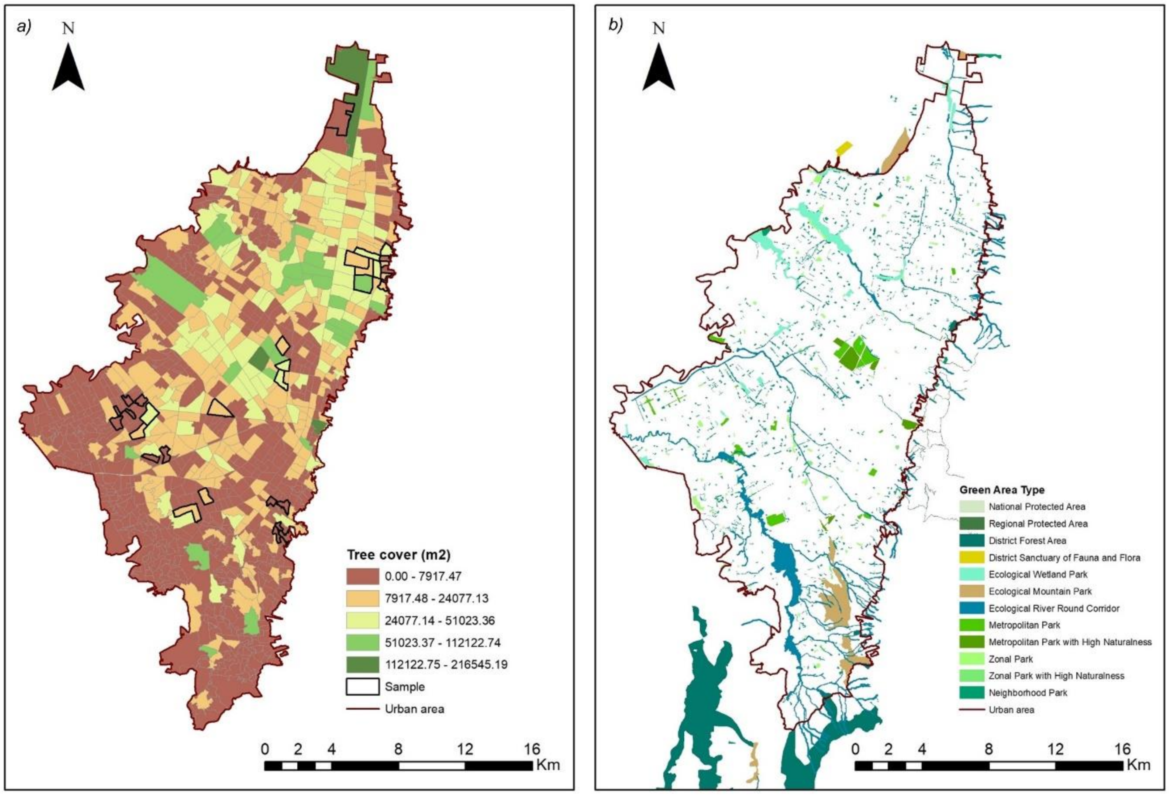

Fig. 2. a) Urban public tree cover per neighborhood. Based on SIGAU (2020). b) Ecological main structure elements and complementary green areas with public access and recreation potential. Based on IDECA (2020) and SDA (2020).

2.2.1 Rainfall interception

To evaluate the capacity of the urban public forest to intercept rainfall, the structure of the trees was considered through the total leaf area (TLA). This variable was calculated at a cell size resolution of 10m x 10m, as the product between the tree cover (m^2) and the leaf area index (LAI) (m^2/m^2) which was obtained with the same spatial resolution using a Sentinel-2 image from 2018. Rainfall interception was evaluated using the Urban Forest Effects Hydro model (UFORE-Hydro) (Wang, Endreny, and Nowak 2008):

$$S = Pe - Pf - E$$

Leave storage S (mm/h) was determined based on the event precipitation Pe (mm), the direct precipitation Pf (mm) –representing the precipitation fraction that is not intercepted by the tree canopy, and the evaporation E (mm), which allows to measure the water quantity returning to the atmosphere. Pf was calculated based on the canopy cover fraction c, which is associated with the LAI of the cells with tree cover and an extinction coefficient k (Wang, Endreny, and Nowak 2008).

$$Pf\ [mm] = Pe\ (1 - c)$$

$$c = 1 - e^{-k*LAI} \qquad k = (0.6 - 0.8)$$

The evaporation was calculated based on S, potential evapotranspiration (Eto) and the maximum storage capacity for a rainfall event $Smax$ that corresponds to 0.2 mm multiplied by LAI (Hirabayashi 2013). ETo was determined using the Hargreaves-Samani methodology (Shahidian et al. 2012).

$$E = \left(\frac{S}{Smax}\right)^{2/3} * \ ETo$$

$$ETo = 0.0135 * \ Rs\ (T + 17.8)$$

The equations were modeled in Python, performing a balance with an hour step, for each cell *I* of each sampled neighborhood *j*, to obtain the annual rainfall interception. Annual storage AS was divided by the neighborhood area, in order to compare the performance of the sampled neighborhoods.

$$AS_j \left[\frac{L}{yr \cdot ha}\right] = \frac{(\sum_i S_i * TLA_i)}{Area_j}$$

Input data for the model such as precipitation and air temperature were obtained hourly for all of 2018. Missing values of precipitation, air temperature and wind speed were completed using a linear weighted combination method with the information of near meteorological stations (Table 1) (Barrera 2004).

2.2.2 Air pollution removal

The capacity of the urban forest canopy to remove $PM_{2.5}$ was calculated using the UFORE-D model, which uses the potential pollution flux as an estimate of the capacity that trees' leaves have of removing $PM_{2.5}$ (Nowak et al. 2013; Nowak and Crane 2000). The flux F ($\mu g/m^{2} \cdot h$) was estimated based on the deposition velocity Vd (m/h), the concentration of $PM_{2.5}$ ($\mu g/m^3$) and the percentage of resuspension R.

$$F\ = Vd * C * (1 - R)$$

Deposition velocity and resuspension were obtained based on their relation with wind speed velocities (Nowak et al. 2013). Hourly precipitation data was also used in this model, since $PM_{2.5}$ accumulated in the leaves is washed out when the leaves reach their maximum storage capacity Smax. As with the UFORE-Hydro model, UFORE-D was also modeled in parallel using Python on an hourly basis for each cell *I* of each sampled neighborhood *j*, to obtain the annual rainfall interception. Annual flux AF was divided by the neighborhood area, in order to compare the performance of the sampled neighborhoods.

$$AF_j \left[\frac{\mu g}{yr \cdot ha}\right] = \frac{(\sum_i F_i * TLA_i)}{Area_j}$$

$PM_{2.5}$ concentrations and wind speed velocity data were obtained hourly from the air quality monitoring network of Bogota (RMCAB) for all of 2018. Missing information was completed using linear interpolations of the existing data when gaps were around 1% of the complete series (MAVDT 2010). Guaymaral and Tunal stations presented gaps of missing information of 6.2% and 3.5% respectively, which were completed using information from 2017.

2.2.3 Recreation potential

Recreation potential was evaluated for publicly accessible green areas above 0.5 ha (see Fig. 2b). Access to recreational green areas was determined based on the areas located at a walking distance (10 minutes' walk) from each neighborhood (TPL, 2020). For more accuracy, we calculated the time spent to walk from the centroid of each sampled neighborhood to the edge of a certain green area. Walking distances were determined using the *Near* tool from ArcMap 10.4.1 and were divided by the walking speed using Irmscher and Clarke (2017) approach:

$$Speed\left[\frac{m}{s}\right] = 0.11 + e^{\frac{-(slope+5)^2}{2*30^2}}$$

The recreation potential RP of neighborhood *j*, was calculated based on the area A of the accessible green area *i*, multiplied by a recreation value weight W of the green area type *k*, that was obtained from the surveys made to the citizens (see Supplementary material), divided by the neighborhood's population.

$$RP_j = \frac{(\sum_i \sum_k A_{ik} * W_k)}{P_j}$$

2.3 Sampling

In order to evaluate the selected ecosystem services and assess their role in the mitigation of the vulnerability and risk to urban stressors (i.e. urban floods, air pollution and low access to green recreation areas), a random sampling stratified by socioeconomic strata was performed for the selection of 30 neighborhoods. Socioeconomic strata were categorized as low (1-2), medium (3-4) and high (5-6), and were assigned to each neighborhood when more than 80% of their blocks fell into a certain category. Neighborhoods that did not meet this criterion were left uncategorized. To obtain a balanced sample, ten neighborhoods were selected from each strata (Fig. 1). Appendix A shows the list of neighborhoods selected in this study.

As precise information regarding air pollution, and meteorological conditions was essential for the ES evaluation, the sampling was limited to neighborhoods located close to the stations of the city's air quality monitoring network (RMCAB), where the collected data had spatial representativeness, and where stations had over 75% of the data validated (see Annex B) (MAVDT 2010).

2.4 Data collection

The information for ES assessment and the vulnerability and risk assessment included the administrative ordering of the city, socioeconomic stratification, green infrastructure (i.e. ecological main infrastructure, public trees and parks), meteorological and environmental data, and satellite imagery (Table 1). The information used for the ES evaluation (meteorological and environmental variables) and the vulnerability and risk analyzes (sensitivity and exposure variables) was collected for 2018, since it was the most recent year with the most complete available information.

Table 1. Data collected for ecosystem services evaluation, and vulnerability and risk assessment.

Data	Units	Source
Neighborhoods	-	IDECA (2019)
Socioeconomic stratification	-	IDECA (2019)
Public tree census	-	SIGAU (2020)
Tree cover	m^2	SIGAU (2020)
Ecological main structure	-	SDA (2020)
Parks	-	IDECA (2020)
$PM_{2.5}$ concentration	$\mu g/m^3$	RMCAB (2018)
Precipitation	mm	RMCAB, IDEAM (2018)
Wind speed	m/s	RMCAB, IDEAM (2018)
Air temperature	°C	RMCAB, IDEAM (2018)
Satellite imagery	-	Planet (2020); ESA (2020)

2.5 Stakeholders

Planning multifunctional green infrastructure in a big city is a complex assignment specially when considering multiple stakeholders' interests and needs. Some cities fail to design public green spaces that respond to the real needs of the citizens or the environment. In many cases, city planners lack an integrated understanding of people demands for green spaces (Hansen and Pauleit 2014; James et al. 2009). To address this issue, three different stakeholder groups were identified and consulted for the prioritization of the ecosystem service: *i)* environmental experts; *ii)* urban planning officials, and *iii)* citizens.

Each group of stakeholders was surveyed to identify the way they prioritize between rainfall management, air pollution removal, and recreation (see Supplementary material). Surveys were based on Meerow and Newell (2019; 2017) and intended to understand the prioritization that different stakeholders made on some criteria associated with the increase of urban resilience. Environmental experts were mainly researchers associated to universities' research centers, or researchers of governmental institutions, like Bogota's Botanical Garden. Experts belonged to different research lines including biodiversity and ecosystem services, water management, air quality, and urban ecology among others. In total, twenty experts participated in this survey.

Contacted urban planning officials worked for administrative departments or governmental institutions. These institutions include the Botanical Garden, the Institute of Urban Development (IDU), the District Planning Secretary (SDP), The Regional Environmental Corporation (CAR), the District Environmental Secretary (SDA) and the Company of Aqueduct and Sewerage (EAAB). Twelve officials from this group of stakeholders were surveyed.

Regarding citizens prioritization, 114 people were asked to complete the survey taking into account the needs they have at their neighborhoods. The surveys were implemented in four parks located near the air quality monitoring stations of Usaquén, Centro de alto rendimiento, Kennedy, and San Cristóbal. The selected parks were chosen to collect information of neighborhoods from the three socioeconomic strata categories. Citizens were also asked to evaluate in a scale from 1 to 7 the recreation value of different green areas types present in Bogotá to evaluate the recreation potential (see Supplementary materials and section 2.2.3).

2.6 Vulnerability and risk assessment

For the assessment of the vulnerability and risk of Bogotá's citizens to floods, air pollution and low access to green recreational areas, an outcome vulnerability framework was chosen to estimate an integral vulnerability index (IVI), and an integral risk index (IRI) for each sampled neighborhood for 2018. Both indexes result from weighting the vulnerability V and risk R to each independent urban stressor *i*. weights Wi were obtained based on the surveys completed by the stakeholders.

$$IVI = \sum_i V_i * W_i$$

$$IRI = \sum_i R_i * W_i$$

The IPCC (2014) defines vulnerability as the propensity or predisposition to be affected negatively, and estimates it as a property of a system depending on its sensitivity and response capacity. Vulnerability expresses when the system is exposed to external or internal impacts leading to the estimation of the risk (Gallopín 2006).

$$Vulnerability = \frac{Sensitivity}{Response\ capacity}$$

$$Risk = Exposure * Vulnerability$$

Several variables where chosen to define the exposure, sensitivity and response capacity sub-indexes for each of the analyzed urban stressors. As the variables are in different scales, they were normalized in a range between 0 and 1. The resulting value for each sub-index is the average of all the variables that conform it.

$$x' = \frac{(x - x_{min})}{(x_{max} - x)}$$

2.6.1 Exposure

Exposure was defined as the level or duration for which a system is in contact to a perturbation (Adger 2006). Table 2 summarizes the variables used to build this sub-index.

Table 2. List of exposure variables for each urban stressor at a neighborhood scale.

Variable	Units	Description	Reference	Source
		Floods		
Number of flood events	number	Number of flood events between 2010 - 2018	Moss et al. (2001)	IDIGER (2020)
Extreme precipitation event	mm	Mean precipitation for an event of 6 hours and return period of 10 years	-	
		Air pollution		

Exposure to $PM_{2.5}$	percentage	Percentage of days in 2018 in for which mean daily concentration was above the recommendations of the WHO (25 μg/m^3)	Suresh and Mukesh (2008)	RMCAB (2018)
Main roads	km	Total distance of main roads (arterial roads)	Makri and Stilanakis (2008); Suresh and Mukesh (2008)	IDECA (2020)
Low access to recreational green areas				
Access to recreational green areas	min/ha	Mean walking time for each hectare of green recreational zones with access (< = 10 min)	TPL (2020)	IDECA (2020); SDA (2020)

2.6.2 Sensitivity

Sensitivity was defined as the amount of transformation in a system per unit of disturbance (Gallopín 2006). Following this definition, two variables were selected to assess the sensitivity to each urban stressor (Table 3).

Table 3. List of sensitivity variables foe each urban stressor at a neighborhood scale.

Variable	Units	Description	Reference	Source
Floods				
Drainage remaining capacity	percentage	Percentage of the stormwater drainage system with a drainage remaining capacity below 15% after a 10 years RP event	Moss et al. (2001); Shepard et al. (2012)	INGETEC (2016); EAAB (2018)
Impermeable floor	percentage	Percentage of impermeable floor	Niehoff et al. (2002)	Planet (2020)
Air pollution				
Population with comorbities	percentage	Percentage of the population obesity, and/or diabitis and/or hypertension	Chu et al. (2018)	ODS (2021)
Population at a sensitive age	percentage	Percentage of the population < 10 years and >= 60 years	OPS (2020)	DANE (2018)
Low access to recreational areas				
Impermeable floor	percentage	Percentage of impermeable floor	Neuvonen et al. (2007)	Planet (2020)
Population at a sensitive age	percentage	Percentage of the population < 10 years and >= 60 years	Neuvonen et al. (2007)	DANE (2018)

2.6.3 Response capacity

Response capacity refers to the ability a system has to adjust or moderate a potential damage (Gallopín 2006). As ES increase resilience and help cope with environmental change, the ES evaluated in this study were used as response capacity variables (Heymans et al. 2019; MADS, 2018; Meerow and Newell 2017; Ahern 2012). For floods, air pollution and low access to green recreational areas, values of annual rainfall retention, $PM_{2.5}$ removal and potential recreation were respectively assigned to assess the vulnerability and risk to each urban stressor.

2.7 Statistical Analyses

To process the information collected with the surveys regarding the ES prioritizations made by environmental experts and urban planning officials, a spreadsheet developed by Goepel (2013) was used. The tool analyzed pairwise-comparisons of ES evaluated in the survey (see Supplementary material) using an Analytical Hierarchical Process which helped obtained the weights for each urban stressor in the estimation of the IVI and IRI. Weights associated to the citizens' prioritization were obtained by, first, adding the importance values that every citizen gave to each ES, and then, calculating the percentage of each ES (individual ES summation from the total summation). ANOVA tests were performed to find differences between the ES prioritization in each socioeconomic strata (low, medium and high), and between the surveyed places to understand if the vulnerability assessment requires to be differentiated by strata or location. Generalized linear models (GLM), ANOVA tests, and box-plots were built to find differences in annual ES values between socioeconomic strata, and differences in IVI and IRI values among stakeholders groups and socioeconomic strata.

Graphical multivariate analysis were carried out and complimented with principal component analysis (PCA) and biplots, to understand the relation between tree cover, access to recreational green areas, IVI and IRI, as well as the relevance of tree cover and access to recreational areas in the construction of the vulnerability and risk indexes.

3. Results

3.1 Ecosystem services

Rainfall interception and air pollution removal still need to be evaluated for each neighborhood. The information regarding all the variables of the models has been collected and the models are being implemented in python to develop a balance of rainfall and PM2.5 removal at resolution of 10m x 10m.

Recreation potential was evaluated using the weights associated to each green area type, which were estimated based on the preferences of 119 citizens that were surveyed (Appendix C). Every green area type was considered to present a mid-high recreation potential and obtained a weight above 0.75, except for the ecological river round corridors (0.55) which were associated with insecurity and litter and therefore received the lowest recreational value. Ecological wetland parks obtained the second lowest weight (0.76) and were also associated with insecurity. Metropolitan parks and zonal parks with high naturalness were considered to have the highest recreational value with weights of 0.95 and 0.92 respectively.

Recreational potential was estimated to be limited for neighborhoods of low strata with a mean vale of 7.85 m^2/inh. Otherwise, medium and high strata neighborhoods presented a higher recreational potential, with mean values of 17.76 m^2/inh and 23.73 m^2/inh respectively, which overpass the recommendations of the WHO (2012) for public green space accessibility (9 – 11 m^2/inh) (Fig. 3). However, no statistically significant differences were found between strata (p-value = 0.32)

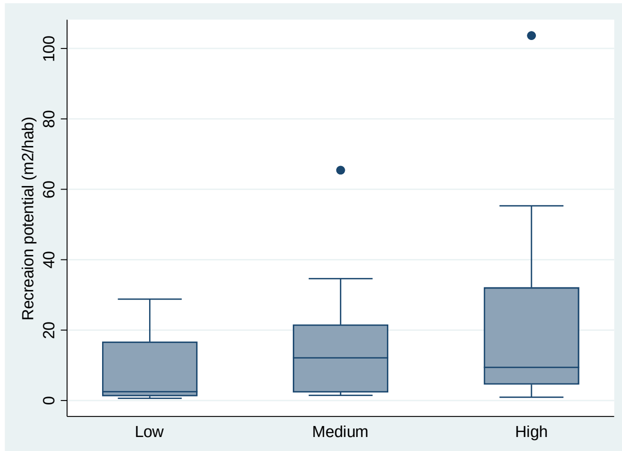

Fig. 3. Recreation potential by socioeconomic strata

3.2 Stakeholder prioritization

In order to establish how stakeholders prioritize between rainfall management, air pollution removal and recreation, 20 experts, 13 urban planners and 114 citizens from different socioeconomic strata were surveyed. The importance that each group gave to an ES were determined as weights with values between 0 and 1. When analyzing citizens' responses, no significant differences were found for any of the assessed ES between strata (p-value > 0.5). However, when analyzing by location, significant differences were found between two of the four selected parks for rainfall management and air pollution removal. Citizens that lived near Country Park gave a lower score for rainfall management than people living close to Gilma Jimenez Park (p-value = 0.023) with values of 0.25 and 0.39 respectively. Otherwise, people that lived close to Gilma Jiménez Park gave a lower score to air pollution removal than people surveyed in Country Park (p-value = 0.031) with values of 0.47 and 0.62 respectively.

Experts as well as urban planners and citizens, prioritize in the first place air pollution removal, followed by rainfall management, and gave the least importance to recreation. Nevertheless, the weights given to each ES varied between stakeholders' groups. Citizens gave the highest score to air pollution removal (0.53) while urban planners and experts almost coincided in their scores (0.43 and 0.41 respectively). For rainfall management, urban planners gave the highest score (0.41), followed by experts and citizens (0.36 and 0.32). Result for recreation were very even for all the stakeholders, urban planners and citizens coincided in a score of 0.16 while experts scored this ES with 0.19 (Fig. 4).

Although there was a high variability within groups of stakeholders, these all ranked the ES in the same order showing some consistency in the needs of the city. However, differences in the weights can translate in differences in vulnerability and risk evaluations, which was determined in the following section.

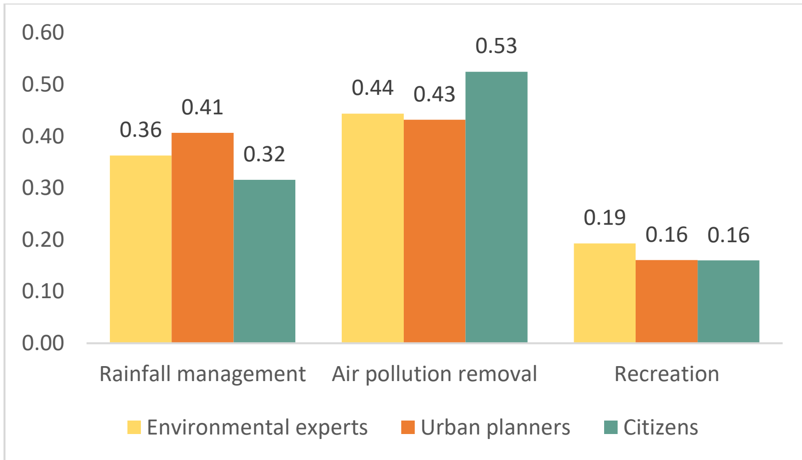

Fig. 4. Stakeholders' prioritization of urban ecosystem services provided by green infrastructure

3.3 Vulnerability and risk assessment

These analyses are still to be performed, as the evaluation of rainfall interception and air pollution removal has not been completely developed, and these values are inputs for the vulnerability and risk indexes.

Fig. 5 summarizes the exposure and sensibility sub-indexes for each environmental stressor.

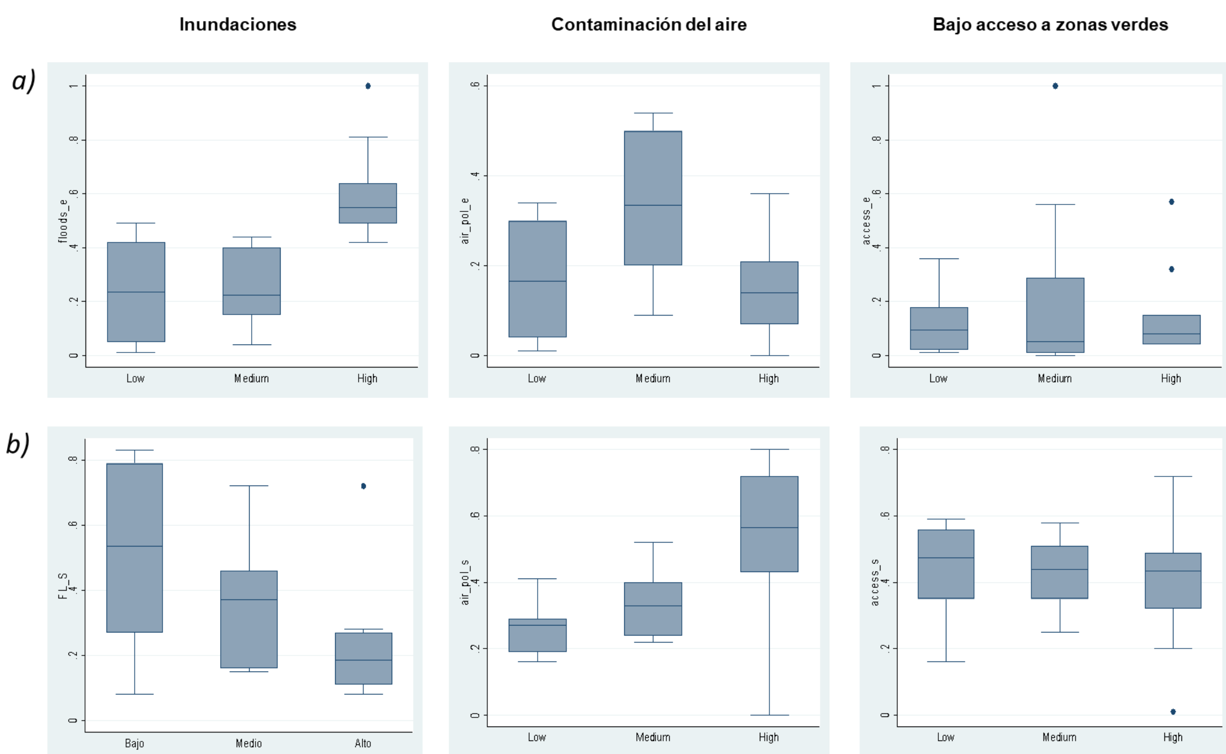

Fig. 5. Floods, air pollution and low access to green areas sub-indexes values by socioeconomic strata for a) exposure and b) sensibility

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Appendix A

Table 3. List of the sample neighborhoods and their respective socioeconomic strata.

No.	Neighborhood	Strata
1	TINTALITO	Low
2	CHUCUA DE LA VACA III	Low
3	LISBOA	High
4	SAN GABRIEL NORTE	High
5	BOSQUE DE PINOS I	High
6	SANTA CATALINA	Medium
7	SAN BLAS II	Low
8	LA CAMPINA	Medium
9	BUENOS AIRES	Low
10	NICOLAS DE FEDERMAN	High
11	SALAZAR GOMEZ	Medium
12	SAN PEDRO	Low
13	SAN BLAS	Low
14	BELLA SUIZA	High
15	GRAN BRITALIA I	Bajo
16	CASABLANCA SUBA	High
17	EL TRIANGULO	Low
18	CIUDAD KENNEDY NORTE	Medium
19	INGLES	Medium
20	MARIA PAZ	Low
21	TUNAL ORIENTAL	Medium
22	EL ROSARIO	Medium
23	GINEBRA	Alto
24	COUNTRY CLUB	High
25	PATIO BONITO II	Low
26	POPULAR MODELO	Medium
27	SANTA BARBARA CENTRAL	High
28	CIUDAD KENNEDY SUR	Medium
29	NARINO SUR	Medium
30	LA CAROLINA	High

Appendix B

Spatial representativeness of each station was determined following the findings of Yatkin et al. (2020) that, under similar urban conditions, found an spatial representativeness of 4 km^2. Taking into account that traffic stations have a narrower site representativeness than background stations, for the six background stations (Usaquén, Centro de alto rendimiento, Kennedy, Carvajal-Sevillana, Tunal and San Cristóbal) a conservative 1 km radius was assigned. For the other traffic and industrial stations a radius equivalent to the distance to the nearest main street or industry, which was 0.29 km for Guaymaral traffic station and 0.33 km for Puente Aranda industrial station were assigned (Rodriguez et al. 2019).

Appendix C

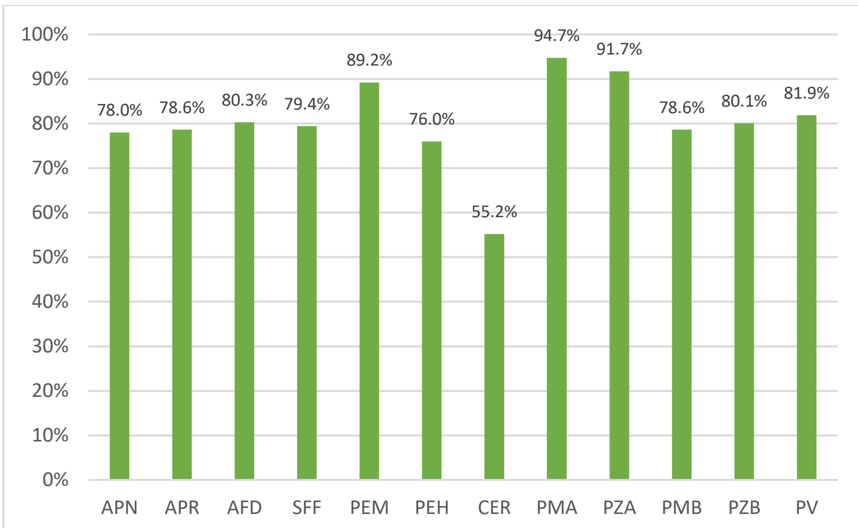

Fig. 6. Recreation value weights of the different green area types.