Availability and accessibility of urban green spaces: the case of the urban zone of Queretaro Metropolitan Area, Mexico

Michelle Farfán Gutiérrez, Andrew Boni Noguez, Alejandro Flamenco-Sandoval, Ayesa Martínez Serrano, Arnoldo Flores-Torres, Ana Karen Godínez Ramírez, and Camilo Alcántara

1. Introduction

At the beginning of the nineteenth century urban population accounted for 2% of the world’s total population. By 2005, that percentage was already over 50 percent (Alberti, 2008). In Mexico, the situation is different. In 1950, approximately 42 percent of the population lived in urban areas. In 1990, it reached 71 percent and in 2015 this figure increased to more than 77 percent (INEGI, 2015a). Faced with the fact that half of humanity currently lives in cities, that this trend will continue to rise and that for most people the future will be urban, the United Nations (UN) in 2015 adopted Agenda 2030 on Sustainable Development. Among the 17 proposed objectives, one refers to sustainable cities and communities, for which a series of goals are defined in order to compensate for the harmful effects of living in them. Goal number 11.7 states that by 2030 universal access to safe and inclusive green areas and public spaces should be provided for women and children, older persons and people with disabilities.

Urban green space has been defined as all natural, seminatural, and artificial ecosystems within, around, and between urban areas at all spatial scales (Benedict & McMahon, 2002; Chang et al., 2015; Tzoulas et al., 2007). In the context of this study, we restricted this to include only those areas that are freely accessible to the general public (also known as public green space, e.g., Dong et al., 2020).

Urban green space – especially the publicly accessible kind – plays a significant role in improving the quality of life of city dwellers and the environment (Baycan-Levent & Nijkamp, 2009; McPhearson et al., 2015). It has been shown that the quantity and accessibility of urban green space is associated with good physical health (Gascon et al., 2015; Van den Berg et al., 2015), mental health (Reklaitiene et al., 2014; McPhearson et al., 2015), and between urban areas at all spatial scales (Benedict & McMahon, 2002; Chang et al., 2015; Tzoulas et al., 2007). In the context of this study, we restricted this to include only those areas that are freely accessible to the general public (also known as public green space, e.g., Dong et al., 2020).

1.1. Socio-environmental functions of urban green space

The increase and preservation of the socio-environmental functions of urban green spaces (UGS) through suitable management is part of the actions of the United Nations’ Sustainable Development Goals. UGS offer benefits to the population in function of their quantity, availability and accessibility. Therefore, we developed a methodology to measure and classify UGS within the urban center of the Queretaro Metropolitan Area in central Mexico. We established one UGS category: public green space and polygon digitization was conducted at 1:1000 scale through on-screen digitization using visual image interpretation. Spatial analysis was carried out in terms of (1) extent (urban green space area); (2) density of UGS (m² of green area/city block); and (3) accessibility to UGS (access for the population at block level as a unit of analysis). Furthermore, cartographic accuracy assessment was conducted in order to validate the generated data. The results show not only the spatial distribution of UGS in the study area but also their spatial relations with the population, in terms of accessibility and density measured against conventional standards. These results may contribute to urban planning regarding UGS, for the improvement of their functions and contributions to the cities’ populations.
walk. Some authors have made spatial inventories of urban green spaces considering these parameters and from these have developed and evaluated a series of indicators that have made it possible to know the situation of this strategic environmental resource in cities. For example, assessments of urban green space of some Mexican cities through the use of geographic information systems have concluded that there is an inadequate provision of green areas per capita as a result of poor urban planning (Peña-Salmón et al., 2014; Ruiz-Luna et al., 2019). Another series of studies has been oriented to estimate its distribution by political-administrative unit (Checa-Artasu, 2016). However, one aspect that has been seldom studied is the accessibility of these spaces since it does not only matter how many square meters of green spaces exist for each inhabitant, but also the distance that must be covered to access them. Recently Torres Pedroza (2018) identified the areas with the greatest and least accessibility to public gardens of the general population and focused the distribution of parks and gardens in the Toluca Valley Metropolitan Area. The results show that high potential accessibility to gardens in the Toluca Metropolitan Area is mainly concentrated in the central area of municipality of Toluca and that accessibility there decreases towards periphery.

The objectives of this study are (1) to estimate the extent of UGS, (2) to evaluate the accuracy of the resulting map, and (3) to estimate UGS density (m² of urban green space/city block) and accessibility (access for the population at block level as a unit of analysis) in the urban zone of the Querétaro Metropolitan Area.

2. Study area

This study was carried out in the urban zone of the Querétaro Metropolitan Area (capital of the state of the same name). It is located near the border with the state of Guanajuato, with the following central coordinates 20°35′N, 100°23′W. It is made up of several localities in conurbations: 14 in the municipality of Querétaro, 5 in the municipality of Corregidora and 1 in the municipality of El Marqués. In total, according to the 2010 General Population and Housing Census (INEGI, 2011) it is made up of 10,501 city blocks inhabited by 828,079 people. Since the mid-1960s, the study area shifted from an agricultural-livestock economy towards industrial activities (PNUMA, 2008), resulting in environmental problems related to urban heat islands (Colunga et al., 2015) and poor air quality (Castaneda-Miranda et al., 2014).

3. Methods

3.1. Generation of public green spaces cartography

The analysis was limited exclusively to public green spaces. These were defined as publicly owned green spaces to which access is not restricted to the general public (UGS hereafter). Such areas are represented by parks, street roundabouts and medians, and are identified by not presenting physical barriers to their access. UGS were mapped using on-screen visual interpretation method (FAO, 1996) with high spatial resolution (0.50 meters) Digital Globe images for the year 2016, accessed through the base map feature in ArcGIS version 10.3. Urban green space polygons were created to a scale of 1:1000. Textural and color criteria used to aid visual interpretation were established with field observation and later confirmed in the validation process. Only areas greater than 40 m² were mapped. Green spaces corresponding to street roundabouts and medians were identified in order to exclude them from the availability and accessibility analyses because of their unsuitability as recreational areas. Analyzed and non-analyzed UGS are differentiated in the green space distribution map.

3.2. Cartographic accuracy assessment

The methodology used for the accuracy assessment is an adaptation of that proposed by Stehman (1996) and Krylov et al. (2019) following recommendations by Olofsson et al. (2013; 2014) and Stehman and Czaplewski (1988). Data were collected for independent validation using two sources. First, by using Google Map on-site pictures (dating from 2016, to assure comparability with mapped data), and then by directly visiting spaces on the field. In total, 640 sites were randomly selected using a stratified random sampling approach. Using the Digital Globe classification, 320 polygons were randomly selected from the 1649 mapped green space polygons (about 20% of the total). An additional 320 sites were randomly selected within the study area where no green spaces were mapped, based on the Queretaro Metropolitan Area map. The field data were collected on the last two weekends of November 2019. The selected sites were visually interpreted using both Google Map on-site pictures and, where available, direct observations on the field. We recorded whether the site was a green public space or not.

An area-adjusted confusion matrix was generated (Card, 1982; Olofsson et al., 2014; Stehman, 1996) in order to calculate (1) the overall accuracy expressed by the Kappa coefficient of agreement; (2) the proportion of pixels correctly allocated; and (3) the user’s and producer’s accuracy for each class. Finally, Kappa coefficients were calculated per class (Stehman, 1996).

3.3. Urban green space availability

3.3.1. Urban green space density

The relationship between the urban population and the amount of green areas is generally expressed as
the green space ratio metric and refers to the availability of UGS within a neighborhood (Xion-Jun, 2009, Haq 2011; Le Texier et al., 2018). According to Le Texier et al. (2018), urban green space density is defined as the amount (number or acreage) of UGS within a city or any sub-parts to provide an aggregate picture of provision to a certain number of residents. In this regard, the urban green space density (UGSD) was calculated and expressed as a percentage, following Reyes and Figueroa (2010), as the ratio of the surface area of urban green space (AUGS) per city block to the total area of the corresponding city block (ACB).

\[ \text{UGSD} = \frac{\text{AUGS}}{\text{ACB}} \]

City blocks (INEGI, 2018) were used as the unit of analysis for population since they are the smallest official geostatistical unit used in Mexico for collecting and registering census data. These may be bounded by streets, roads, natural features, or other land boundaries (INEGI, 2015b) and are thus of inconsistent shape and varying surface area (ranging from 28 m² to 1,340,433 m² in the study area). Nevertheless they offer the highest possible resolution for a local-scale analysis such as this. The spatial delimitation of city blocks and population data were taken from the 2010 General Population and Housing Census (INEGI, 2011).

### 3.3.2. Urban green space accessibility: a network analysis approach

Urban green space accessibility (UGSA) estimation was based on the definition provided by Gregory (1986). This refers to the ease with which a site or service may be reached or obtained. It can thus be said to measure the relative opportunity for interaction or contact with a given phenomenon such as a park. According to Le Texier et al. (2018), a variety of accessibility indices have been defined using network approaches and are mostly preferred to simpler Euclidean distances in order to avoid overestimation of accessibility. In this study, urban green space accessibility was measured with the ArcGIS 10.5 Network Analyst module. With this module it is possible to identify service areas around any location within a network. In other words, a network service area that incorporates all accessible streets within a given impendence (such as travel time or distance) range. For this study a maximum travel distance of 300 m was considered, following the standard proposed by English Nature (Handley et al., 2003), measured from the center of each urban green space, considering the street network of the urban zone of the Queretaro Metropolitan Area (INEGI, 2010). This measure was broken down into 100-meter intervals for a clearer understanding of accessibility within the 300 m range. Travel distances were considered from the center of each green space (and not the points of access located at the edges) as this better reflects the distance needed to be traveled in order to actually make significant use of the area and not merely reaching its border. Finally, population residing within each distance range was calculated. Population data was taken from the 2010 General Population and Housing Census (INEGI, 2011).

### 4. Results

Results are presented in three maps which describe, respectively, urban green space distribution, urban green space density and public urban green space accessibility. Map accuracy assessment for the first map resulted in a Kappa coefficient of agreement of 82.83%, and producer and user accuracies of 80.50% and 83.57%, respectively. The proportion of correctly allocated pixels is 75.8%.

Altogether, the urban zone of the Queretaro Metropolitan Area contains 795.34 ha of public urban green space. Queretaro’s UGS represent only 5.18% of its total surface (study area total surface: 15,367 ha). The area corresponding to street roundabouts and medians is 246.49 ha. The remaining 548.86 ha of public greenspace includes mainly parks and other areas accessible to the general public. This last subset was the basis for the availability and accessibility analyses.

Regarding urban green space density (Table 1), there exist no universal or standard criteria to establish categories regarding this metric, since each city has its own environmental and geographic characteristics (Sorensen et al., 1997). Significantly, 9462 city blocks out of a total of 10,501 completely lack urban green space (green space density = 0%), which corresponds to 87% of the total population. By classifying the rest of the data with Jenks natural breaks optimization into five classes (as presented in the map legend and Table 1), the lower two concentrate most of the remaining city blocks (and population). Alternate classification show that of a total of 828,079 people living in the study area, only about 1266 people (0.15% of the total population) live in blocks with more than 50% density of green space. On the other hand, a total of 63,280 people (7.6% of the total population) live in areas with 1% to 10% of green space in their respective city blocks.

| Urban green space density (%) | City blocks |
|-----------------------------|------------|
| Population                  | City blocks |
| 0                           | 725,738    | 9462 |
| 0.0001–10.58                | 63,280     | 548  |
| 10.59–21.44                 | 20,984     | 223  |
| 21.45–36.26                 | 10,891     | 133  |
| 36.27–59.75                 | 5920       | 90   |
| 59.76–92.29                 | 1266       | 45   |
| Total                       | 828,079    | 10,501 |

Table 1. Urban green space density (%) by city block of the urban zone of the Queretaro Metropolitan Area, Mexico. Classes were defined by Jenks natural breaks optimization.
In terms of green space accessibility, it was possible to estimate that there is a total of 306,317 inhabitants who live outside a 300-m distance threshold (Table 2). Thus, 35.4% of the population lives 300 m farther away from the closest urban green space.

5. Conclusion

The three maps herein presented offer a detailed view of the current state of urban green space spatial distribution and availability within the Queretaro Metropolitan Area. The low quantity of UGS in the city as a whole is further accentuated by an uneven distribution, resulting in large areas (and correspondingly high proportions of the city’s population) completely devoid of accessible urban green spaces. This is most starkly visible in the northwestern section of the city.

The methodology (with the obvious drawback of being time-consuming) used to create the UGS main map, results in a high-accuracy dataset useful for further spatial analysis regarding UGS distribution including, for example, socio-economic variables. Thus, for the specific case of the Queretaro Metropolitan Area, this is a first assessment of UGS. A deeper understanding of ecological and social implications of the city’s urban green spaces would require further analyses built upon this dataset and results.

The use of standard metrics for UGS density and accessibility may contribute to a more systematic assessment of UGS distribution and availability in metropolitan areas in other cities and regions for both academic and land-planning purposes.

Software

The data were displayed, processed, and analyzed using ESRI ArcGIS 10.3, except for the network analysis, which was processed with the ArcGIS10.5 Network Analyst module.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Universidad de Guanajuato through the Dirección de Apoyo a la Investigación y al Posgrado (DAIP) in the 2019 application process under the project “Análisis de la configuración del espacio verde urbano mediante Sistemas de Información Geográfica en dos zonas metropolitanas del Bajío, León y Querétaro”. Full support for publication costs (open access fee) was provided by the Universidad de Guanajuato, through its División de Ingenierías.

ORCID

Michelle Farfán Gutiérrez  http://orcid.org/0000-0002-4948-1453
Andrew Boni Noguez  http://orcid.org/0000-0001-8536-6500
Alejandro Flamenco-Sandoval  http://orcid.org/0000-0002-7700-8591
Ayesa Martínez Serrano  http://orcid.org/0000-0002-6987-6815
Arnoldo Flores-Torres  http://orcid.org/0000-0002-3801-6396
Ana Karen Godínez Ramírez  http://orcid.org/0000-0002-4857-8579
Camilo Alcántara  http://orcid.org/0000-0001-5820-5365

References

Alberti, M. (2008). Advances in urban ecology integrates human and ecological process in urban ecosystems. Springer-Verlag.

Baycan-Levent, T., & Nijkamp, P. (2009). Planning and management of urban green spaces in Europe: comparative analysis. Journal of Urban Planning and Development, 135(1), 1–12. https://doi.org/10.1061/(ASCE)0733-9488(2009)135:1(1)

Benedict, M. A., & McMahon, E. T. (2002). Green infrastructure: smart conservation for the 21st century. Renewable resources journal, 20(3), 12–17.

Card, D. H. (1982). Using known map category marginal frequencies to improve estimates of thematic map accuracy. Photogrammetric Engineering & Remote Sensing, 48(3), 431–439.

Castaneda-Miranda, A. G., Böhnel, H. N., Molina-Garza, R. S., & Chaparro, M. A. (2014). Magnetic evaluation of TSP-filters for air quality monitoring. Atmospheric environment, 96, 163–174. https://doi.org/10.1016/j.atmosenv.2014.07.015

Chang, Q., Liu, X., Wu, J., & He, P. (2015). MSPA-based urban green infrastructure planning and management approach for urban sustainability: Case study of Longgang in China. Journal of Urban Planning and Development, 141(3), A5014006. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000247

Checa-Artasu, M. (2016). Las áreas verdes en la Ciudad de México. Las diversas escalas de una geografía urbana. Biblio3W. Revista Bibliográfica De Geografía Y Ciencias Sociales, XXI(1.159), 1–22.

Colunga, M. L., Cambrón-Sandoval, V. H., Suzán-Azpiri, H., Guevara-Escobar, A., & Luna-Soria, H. (2015). The role of urban vegetation in temperature and heat island effects in Querétaro city, Mexico. Atmosfera, 28(3), 205–218. https://doi.org/10.20937/ATM.2015.28.03.05

Dong, Y., Liu, H., & Zheng, T. (2020). Does the connectivity of urban public green space promote its use? An empirical study of Wuhan. International journal of...
environmental research and public health, 17(1), 297. https://doi.org/10.3390/jiernph17010297
FAO. (1996). Forest Resources Assessment 1990. Survey of tropical forest cover and study of change processes. Number 130, Rome.
Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasencia, A., & Nieuwenhuijsen, M. J. (2016). Residential green spaces and mortality: a systematic review. Environment international, 86, 60–67. https://doi.org/10.1016/j.envint.2015.10.013
Gregory, D. (1986). Accessibility. In R. J. Johnston, D. Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasencia, A., & Nieuwenhuijsen, M. J. (2016). Residential green spaces and mortality: a systematic review. Environment international, 86, 60–67. https://doi.org/10.1016/j.envint.2015.10.013
Gregory, D., & Figueroa, I. M. (2010). Distribucion, superficie y accesibilidad de las áreas verdes en Santiago de Chile [Distribution, size and accessibility of green areas in Santiago, Chile], EURE, 36(109), 89–110. http://dx.doi.org/10.4067/S0250-7161201000000004
Krylov, A., Steininger, M. K., Hansen, M. C., Potapov, P. V., INEGI. (2015b). Instituto Nacional de Estadística y Geografía (INEGI) Recorrido de Actualización del Marco Geoestadístico Nacional, el Entorno Urbano y las Características de las Localidades. Manual del técnico de actualización. INEGI. (2018). Marco Geoestadístico, febrero 2018. Archivo vectorial. https://www.inegi.org.mx/app/biblioteca/ficha.html?fcupe=889463526636.
Krylov, A., Steininger, M. K., Hansen, M. C., Potapov, P. V., Stehman, S. V., Gost, A., … Ellis, P. (2019). Contrasting tree-cover loss and subsequent land cover in two neotropical forest regions: sample-based assessment of the Mexican Yucatán and Argentine Chaco. Journal of Land Use Science, 1–16. https://doi.org/10.1080/1747423X.2019.1569169
Le Texier, M., Schiel, K., & Caruso, G. (2018). The provision of urban green space and its accessibility: Spatial data effects in Brussels. PLoS ONE, 13(10), e0204684. https://doi.org/10.1371/journal.pone.0204684
Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. Health Place, 15(2), 586–595. https://doi.org/10.1016/j.healthplace.2008.09.006
McPherson, T., Andersson, E., Elmqvist, T., & Frantzeskaki, N. (2015). Resilience of and through urban ecosystem services. Ecosystem Services, 12, 152–156. https://doi.org/10.1016/j.ecoser.2014.07.012
Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, 148, 42–57. https://doi.org/10.1016/j.rse.2014.02.015
Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. Remote Sensing of Environment, 129, 122–131. https://doi.org/10.1016/j.rse.2012.10.031
Peña-Salmon, C., Leyva-Camacho, O., Rojas-Caldecas, R., Alonso-Navarrete, A., & Ibagüez-Ayón, P. (2014). The identification and classification of green areas for urban planning using multispectral images at Baja California, Mexico. WIT Transactions on Ecology and the Environment, 191, 611–621. https://doi.org/10.2495/SCI40511
Programa de las Naciones Unidas Para el Medio Ambiente (PNUMA). (2008). Perspectivas del medio ambiente urbano, GEO Zona Metropolitana Querétaro.
Reklaiciene, R., Grazuleviciene, R., Dedele, A., Virviciute, D., Vensloviene, J., Tamosiunas, A., … Bernotiene, G. (2014). The relationship of green space, depressive symptoms and perceived general health in urban population. Scandinavian journal of public health, 42(7), 669–676. https://doi.org/10.1177/140349814544494
Reyes, S., & Figueroa, I. M. (2010). Distribucion, superficie y accesibilidad de las áreas verdes en Santiago de Chile [Distribution, size and accessibility of green areas in Santiago, Chile], EURE, 36(109), 89–110. http://dx.doi.org/10.4067/S0250-7161201000000004
Ruiz-Luna, A., Bautista Bautista, R., Hernández-Guzmán, R., & Camacho-Valdez, V. (2019). Uneven distribution of urban green spaces in a coastal city in northwest Mexico. Local Environment, 24(5), 458–472. https://doi.org/10.1080/13549839.2019.1590324
Sorensen, M., Barzetti, V., Keipi, K., & Williams, J. (1997). Good practices for urban greening. Inter-American Development Bank. https://publications.iadb.org/publications/english/document/Good-Practices-for-Urban-Greening.pdf (accessed March 17 2021).
Stehman, S. V. (1996). Estimating the Kappa Coefficient and its Variance under Stratified Random Sampling. Society, 62(4), 401–407.
Stehman, S. V., & Czaplewski, R. L. (1998). Design and Analysis for Thematic Map Accuracy Assessment: Fundamental Principles. Science, 344(January), 331–344. https://doi.org/10.1016/S0033-4257(98)00010-8
Torres Pedroza, L. A. (2018). Accesibilidad a jardines en la zona metropolitana de Toluca. Centro de Planeación Estratégica y Prospectiva Política, S.C. https://ceplan.com.mx/accesibilidad-a-jardines-en-la-zona-metropolitana-de-toluca/.
Tzoukas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kązmierczak, A., Niemela, L., & James, P. (2007). Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and urban planning, 81(3), 167–178. https://doi.org/10.1016/j.landurbplan.2007.02.001
United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&referer=english&Lang=E
Van den Berg, M., Wendel-Vos, W., Van Poppel, M., Kemper, H., Van Mechelen, W., & Maas, J. (2015). Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. Urban Forestry & Urban Greening, 14(4), 806–816. https://doi.org/10.1016/j.ufug.2015.07.008
WHO. (2012). World Health Organization, Health Indicators of sustainable cities in the Context of the Rio +20 UN Conference on Sustainable Development. WHO/HSE/PHE/7.6.2012f, 2012.
Wood, L., Hooper, P., Foster, S., & Bull, F. (2017). Public green spaces and positive mental health—investigating the relationship between access, quantity and types of parks and mental wellbeing. Health & place, 48, 63–71. https://doi.org/10.1016/j.healthplace.2017.09.002
Xion-Jun, W. (2009). Analysis of Problems in Urban Green Space Planning in China. Journal of forestry Research, 20(1), 79–82. https://doi.org/10.1007/s11676-009-0014-2