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Research Note

Soil access is an equity issue for urban climate resilience

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HIGHLIGHTS

- Nature-based solutions (NBS) help build resilience to climate change.
- Soil is needed to implement NBS, but soil availability is uneven across LA County.
- Sites with higher social vulnerability have less soil area.
- Sites with less soil area have more fragmented and irregularly shaped soil patches.
- Access to soil is an important equity issue that may limit opportunities for NBS.

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ABSTRACT

Nature-based solutions (NBS) are increasingly used to build urban climate resilience by employing natural features and processes. Implementing NBS in urban residential areas relies on the availability of unsealed soil surfaces. Here we investigate how soil is distributed at fine spatial scales across Los Angeles County, the second largest metropolitan area in the United States, to examine the potential for NBS to be realized equitably. We delineate soil patches in residential areas across a range of socioeconomic settings and urban forms, and then compare soil patch metrics to social vulnerability. Results demonstrate that areas with higher social vulnerability have less total soil area that is also more fragmented and more irregularly shaped. Reduced soil area and soil fragmentation may limit the potential for implementing NBS. As soil availability varies across Los Angeles County in relation to social vulnerability, this study foregrounds soil access as an urban equity issue.

1. Introduction

Urban areas face a host of environmental challenges shaped by both historical legacies and contemporary city making that are amplified by climate change (Hobbie & Grimm, 2020; Leichenko, 2011). For example, cities experience urban heat islands and altered hydrological regimes that threaten human wellbeing and the resilience of social-ecological systems. Nature-based solutions (NBS) are designed to improve social-ecological outcomes by employing natural features (e.g., plants, soils, wetlands) and natural processes (e.g., evapotranspiration, stormwater infiltration, nutrient cycling). Whereas gray infrastructure is often built to perform a single function such as a pipe designed to convey stormwater, NBS can provide multiple ancillary co-benefits alongside their primary purposes (Osaka et al., 2021; Sowińska-Świerkosz & García, 2022). For instance, trees reduce urban heat island effects through shading and evapotranspiration, and they provide multiple co-benefits like aesthetic value, noise attenuation, and reduced stormwater runoff (Berland et al., 2017; Rahman et al., 2020).

The majority of NBS in residential areas are installed directly in the ground, so adequate areal extent and suitable configuration of soil are prerequisites to implementing NBS. In addition to supporting vegetation growth, urban soils serve other important functions such as water

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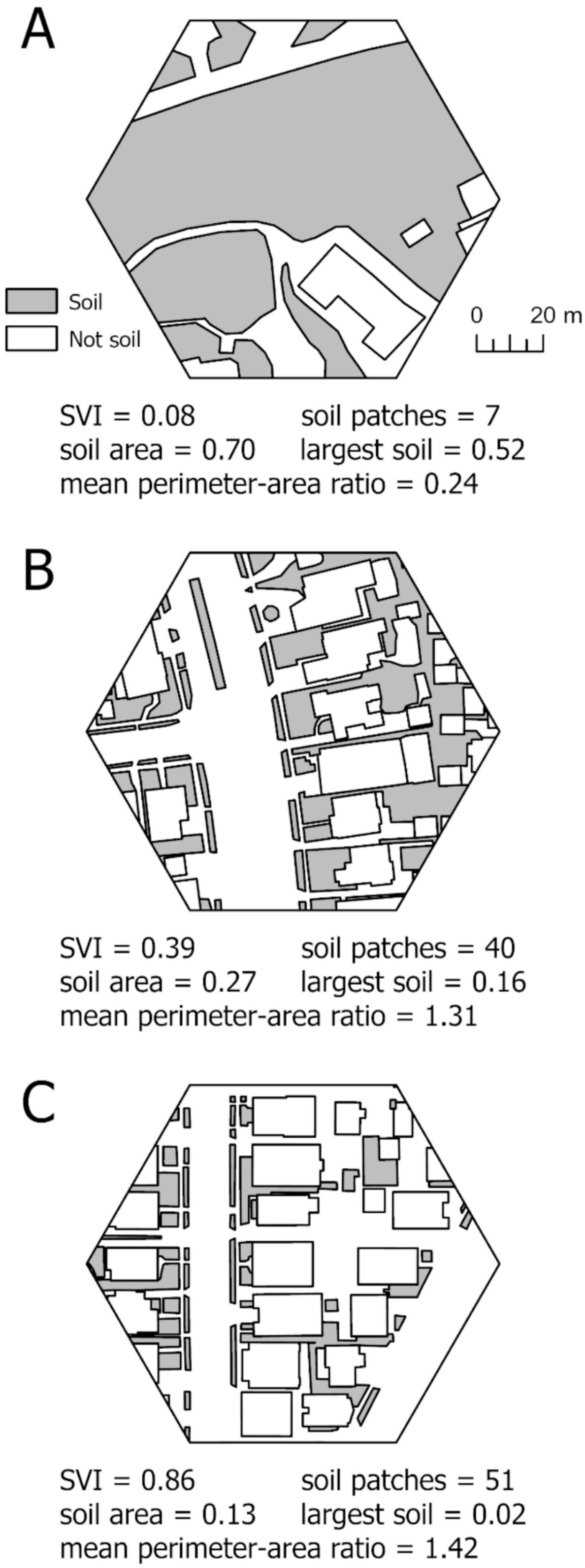

Fig. 1. Examples of delineated hexagons from locations representing low (A), medium (B), and high (C) social vulnerability index (SVI) values. Soil area and largest soil patch are given as proportions of the 1-ha hexagon. Mean perimeter-area ratio is calculated for soil patches only. These examples are drawn from the neighborhoods of Rolling Hills (A), Pico-Robertson Los Angeles (B), and South-Central Los Angeles (C).

regulation, carbon storage, and maintaining biodiversity (Calzolari et al., 2020). Yet the importance of soils is underappreciated in planning for urban climate resilience (Shankar et al., 2024). Impervious surfaces proliferate in cities, reducing the extent of unsealed soil surface and fragmenting its configuration. Moreover, impervious surfaces and attendant problems like urban heat islands and flooding are disproportionately concentrated in socially vulnerable areas (Hsu et al., 2021; Hughes et al., 2022), suggesting that the impacts of impervious cover, in the context of present and future climate change, could contribute to increasing inequities. This situates urban soil availability as an important – but understudied – equity issue.

Studies have demonstrated inequitable distributions of urban vegetation and greenspace at neighborhood scales (e.g., Gerrish & Watkins, 2018). Considerably less attention has been paid to the availability of soil surfaces that are needed to grow vegetation, particularly at the fine spatial scales relevant to implementing NBS in residential landscapes where they can directly benefit residents. Larger soil patches with more compact patch shapes should support a broader range of NBS, and by extension, ecosystem services. For example, a large-statured shade tree may be suitable for planting in a square or circular soil patch, but not in a long and narrow soil patch of equivalent area (City of Los Angeles, 2025). Geospatial data resources including high-resolution orthophotos permit delineation of soil patches at the fine sub-parcel scales at which NBS can be implemented in urban residential areas. Here, we characterize soil patches in residential areas across a range of socioeconomic settings and urban forms in Los Angeles County, California. We compare soil patch metrics to social vulnerability. In doing so, we foreground soil access as an urban equity issue, insofar as access to soil area is a necessary precursor to building climate resilience through NBS.

2. Materials and methods

The study was conducted in the southern portion of Los Angeles County, California, including Santa Clarita and areas south of the San Gabriel Mountains (Supplementary Fig. 1). This includes the heart of Greater Los Angeles, the second largest metropolitan area in the USA. We created a tessellation of 1-hectare hexagons covering the study area to serve as candidate study sites. Hexagons were used instead of squares to reduce the likelihood of capturing artifacts of urban form such as gridded street networks. Hexagons with ≥60 % residential land not including public right-of-way were candidates for study site selection. Residential land was defined as property parcels with 1–4 residential units according to county property data (County of Los Angeles, 2023), and of these 91.5 % were single housing units.

Soil delineation was conducted for a random selection of hexagons. Analysts divided the entire 1-ha hexagon into polygons representing soil, buildings, impervious surface, and water. Soil included vegetated ground surfaces (primarily turf grass and trees/shrubs), landscaping or rockscaping (primarily mulch or stone aggregate covers), bare soil, and artificial turf. These soil types are all pervious surfaces that could potentially be converted to NBS without the need to depave or raze structures. Building footprint polygons from County of Los Angeles (2023) were provided to analysts to aid in delineation. Analysts digitized polygons on-screen at a scale of ~1:350 in ArcGIS Pro (ESRI, Redlands, CA) using high-resolution imagery from LARIAC 6 (2023). The imagery consisted of 4-inch (10-cm) resolution orthophotos acquired in fall 2021 in both natural color and color-infrared. The minimum delineated polygon size was ~0.2 m^2. Because we were interested in the size and shape of soil polygons, bias could be introduced, for example, if a large soil polygon was located at the edge of the hexagon to be delineated. To reduce this bias, any soil polygons originating inside the 1-ha hexagon boundary and extending out beyond the 1-ha hexagon were delineated in their entirety or up to the boundary of a 2-ha hexagon centered on the original hexagon, whichever came first. Delineated hexagon files were collected from five analysts, and post-processed to ensure data completeness, integrity, and consistency across analysts.

Table 1
Spearman correlations among soil metrics and social vulnerability for study locations in Los Angeles County. All correlations are significant at $p < 0.0001$.

	Soil area (proportion)	Soil patches (n)	Largest soil patch	Mean soil perimeter-area ratio	Social Vulnerability Index
Soil area (proportion)	1				
Soil patches (n)	−0.89	1			
Largest soil patch	0.95	−0.91	1		
Mean soil perimeter-area ratio	−0.65	0.73	−0.61	1	
Social Vulnerability Index	−0.58	0.57	−0.57	0.35	1

We calculated four soil metrics to quantify the abundance and configuration of soil surfaces in delineated hexagons. We counted the number of soil patches, and we calculated the proportional area of the 1-ha hexagon that was classified as soil. The largest patch captured the size of the largest soil polygon, including portions of the polygon that extended into the surrounding 2-ha hexagon when applicable. Finally, we computed the mean perimeter-area ratio for soil patches to characterize the complexity of soil patch shapes; larger perimeter-area ratios indicate more irregularly shaped patches. Together, these metrics capture the overall availability, fragmentation, and configuration of soil.

To explore dimensions of equity in the spatial heterogeneity of soil availability, we characterized social vulnerability using the CDC/ATSDR Social Vulnerability Index (SVI) (US Department of Health, Human Services, 2022). The SVI ranges from 0 (lowest vulnerability) to 1 (highest vulnerability). It is a composite of 16 US Census variables addressing the following four themes: socioeconomic status, household characteristics, racial and ethnic minority status, and housing type and transportation. SVI is reported for census tract polygons, and we used inverse distance weighting to interpolate SVI estimates for each 1-ha hexagon centroid. We calculated Spearman correlations and created scatterplot graphs with loess curves to understand relationships among the four soil metrics and social vulnerability.

3. Results

We delineated soil polygons at high-resolution for 172 random hexagons in the southern Los Angeles County study area. Hexagons contained between 1–66 soil patches (median = 16), and soil covered between 5.6–100.0 % of the 1-ha hexagon area (median = 46.8 %). The median size of the largest soil patch was 0.46 ha, with a range of 0.02–2.00 ha (soil patches extending beyond the 1-ha hexagon were delineated outward to a maximum of 2.00 ha). Mean soil perimeter-area ratio ranged from 0.03 to 3.73 (median = 1.01). Our sample covered a broad range of SVI values (0.04–0.96; median = 0.34). Fig. 1 shows characteristic hexagons at different levels of SVI.

The number of soil patches was negatively correlated with soil area and the largest soil patch, and positively correlated with soil perimeter-area ratio (Table 1). Soil area was positively correlated with the size of the largest soil patch, and negatively correlated with perimeter-area ratio. The size of the largest soil patch was negatively correlated with soil perimeter-area ratio. SVI was positively correlated with the number of soil patches and perimeter-area ratio, and negatively correlated with soil area and the size of the largest soil patch (Fig. 2, Table 1). All Spearman correlations were significant at $p < 0.0001$.

4. Discussion

Delineating available soil surfaces at fine scales helps illustrate the opportunities and constraints for implementing NBS as a climate adaptation strategy in urban residential areas. Our findings contribute to the literature by emphasizing sub-parcel patterns in soil abundance and configuration that are relevant for NBS planning and implementation in residential landscapes. We observed that locations with less overall soil area had soil polygons that were smaller, more fragmented, and more irregularly shaped. Importantly, these locations also had generally higher social vulnerability. Sites with lower social vulnerability had more soil area with larger soil patches and less complex patch shapes.

This study foregrounds the unequal distribution of available soil surfaces as an equity issue in Los Angeles County. As the region confronts climate change and related environmental challenges, unpaved soil surfaces could be used to implement NBS that build social-ecological resilience. However, neighborhoods with higher social vulnerability do not have the large, contiguous soil patches that are more amenable to implementing a wide range of NBS. We expect these patterns could generally apply in other urban contexts, because studies have shown broad homogenization of urban form (Lemoine-Rodríguez et al., 2020), similar patterns in environmental justice outcomes across cities (Schwarz et al., 2015), and legacies of redlining and other historical factors that are generalizable across cities (Lane et al., 2022; Locke et al., 2021).

As cities develop climate adaptation plans featuring NBS, the availability of soil surface and its configuration is a foundational consideration alongside other technical and programmatic challenges associated with NBS (McPhearson et al., 2022; Seddon, 2022; Treglia et al., 2022).

While the availability of unsealed soil is a prerequisite to implementing NBS, soil properties like permeability and nutrient availability influence suitability for NBS. But regardless of soil properties, achieving equitable outcomes using urban NBS stands to be particularly difficult in socially vulnerable neighborhoods based on limited soil surface availability alone. Based on our findings of smaller, more fragmented, and more irregularly shaped soil patches in neighborhoods experiencing higher social vulnerability, NBS may require more extensive changes to

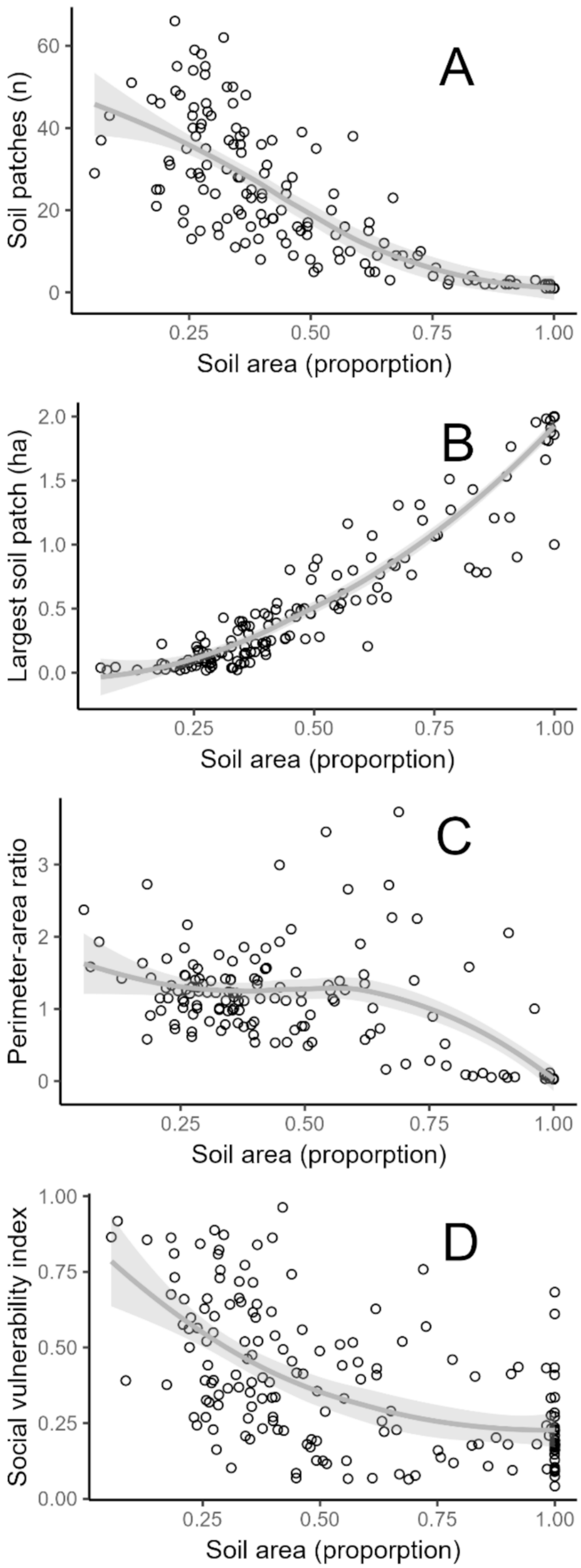

Fig. 2. Relationships between proportional soil area and (A) number of soil patches, (B) largest soil patch, (C) soil mean perimeter-area ratio, and (D) Social Vulnerability Index (SVI). Lines represent loess curves with 95 % confidence intervals.

urban policy and planning to reimagine and transform areas with limited soil access.

CRediT authorship contribution statement

Adam Berland: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Dustin L. Herrmann:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization. **Dexter H. Locke:** Writing – review & editing, Methodology, Conceptualization. **Kirsten Schwarz:** Writing – review & editing, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2025.105395.

Data availability

The data set is available at https://doi.org/10.17632/w222dby553.1.

References

Berland, A., Shiflett, S. A., Shuster, W. D., Garmestani, A. S., Goddard, H. C., Herrmann, D. L., & Hopton, M. E. (2017). The role of trees in urban stormwater management. *Landscape and Urban Planning, 162*, 167–177. https://doi.org/10.1016/j.landurbplan.2017.02.017

Calzolari, C., Tarocco, P., Lombardo, N., Marchi, N., & Ungaro, F. (2020). Assessing soil ecosystem services in urban and peri-urban areas: From urban soils survey to providing support tool for urban planning. *Land Use Policy, 99*, Article 105037. https://doi.org/10.1016/j.landusepol.2020.105037

City of Los Angeles. (2025). Street tree selection guide. https://streetsla.lacity.org/bss-ufd-street-tree-selection-guide. Accessed 4/4/2025.

County of Los Angeles. (2023). County of Los Angeles enterprise GIS. https://egis-lacounty.hub.arcgis.com/. Accessed 10/15/2024.

Gerrish, E., & Watkins, S. L. (2018). The relationship between urban forests and income: A meta-analysis. *Landscape and Urban Planning, 170*, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005

Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B, 375*(1794), Article 20190124. https://doi.org/10.1098/rstb.2019.0124

Hsu, A., Sheriff, G., Chakraborty, T., & Manya, D. (2021). Disproportionate exposure to urban heat island intensity across major US cities. *Nature Communications, 12*(1), 2721. https://doi.org/10.1038/s41467-021-22799-5

Hughes, S., Dobie, S., Schwarz, K., LaMarr LeMee, G., Lane, M., & Gonzalez, A. (2022). Centering racial justice in urban flood resilience policy and planning: Tools for practitioners. *Environmental Justice, 15*(2), 83–89. https://doi.org/10.1089/env.2021.0045

Lane, H. M., Morello-Frosch, R., Marshall, J. D., & Apte, J. S. (2022). Historical redlining is associated with present-day air pollution disparities in U.S. cities. *Environmental Science & Technology Letters, 9*(4), 345–350. https://doi.org/10.1021/acs.estlett.1c01012

LARIAC 6. (2023). LARIAC Orthogonal Imagery. https://lariac-lacounty.hub.arcgis.com/. Accessed 10/15/2024.

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability, 3*(3), 164–168. https://doi.org/10.1016/j.cosust.2010.12.014

Lemoine-Rodríguez, R., Inostroza, L., & Zepp, H. (2020). The global homogenization of urban form. An assessment of 194 cities across time. *Landscape and Urban Planning, 204*, Article 103949. https://doi.org/10.1016/j.landurbplan.2020.103949

Locke, D. H., Hall, B., Grove, J. M., Pickett, S. T. A., Ogden, L. A., Aoki, C., Boone, C. G., & O'Neil-Dunne, J. P. M. (2021). Residential housing segregation and urban tree canopy in 37 US cities. *NPJ Urban Sustainability, 1*, 15. https://doi.org/10.1038/s42949-021-00022-0

McPhearson, T., Cook, E. M., Berbés-Blázquez, M., Cheng, C., Grimm, N. B., Andersson, E., & Troxler, T. G. (2022). A social-ecological-technological systems framework for urban ecosystem services. *One Earth, 5*(5), 505–518. https://doi.org/10.1016/j.oneear.2022.04.007

Osaka, S., Bellamy, R., & Castree, N. (2021). Framing "nature-based" solutions to climate change. *Wiley Interdisciplinary Reviews: Climate Change, 12*(5), e729.

Rahman, M. A., Stratopoulos, L. M., Moser-Reischl, A., Zölch, T., Häberle, K. H., Rötzer, T., & Pauleit, S. (2020). Traits of trees for cooling urban heat islands: A meta-analysis. *Building and Environment, 170*, Article 106606. https://doi.org/10.1016/j.buildenv.2019.106606

Schwarz, K., Fragkias, M., Boone, C. G., Zhou, W., McHale, M., Grove, J. M., & Cadenasso, M. L. (2015). Trees grow on money: Urban tree canopy cover and environmental justice. *PLoS ONE, 10*(4), Article e0122051. https://doi.org/10.1371/journal.pone.0122051

Seddon, N. (2022). Harnessing the potential of nature-based solutions for mitigating and adapting to climate change. *Science, 376*(6600), 1410–1416. https://doi.org/10.1126/science.abn9668

Shankar, M., Ng, M., Rogers, M., Cook, E. M., Herrmann, D. L., & Schwarz, K. (2024). Unearthing the role of soils in urban climate resilience planning. *Nature Sustainability*. https://doi.org/10.1038/s41893-024-01436-1

Sowińska-Świerkosz, B., & García, J. (2022). What are nature-based solutions (NBS)? Setting core ideas for concept clarification. *Nature-Based Solutions, 2*, Article 100009. https://doi.org/10.1016/j.nbsj.2022.100009

Treglia, M. L., Piland, N. C., Leu, K., Van Slooten, A., & Maxwell, E. N. (2022). Understanding opportunities for urban forest expansion to inform goals: Working toward a virtuous cycle in New York City. *Frontiers in Sustainable Cities, 4*, Article 944823. https://doi.org/10.3389/frsc.2022.944823

US Department of Health & Human Services. (2022). CDC/ATSDR Social Vulnerability Index. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html. Accessed 10/15/2024.