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Walking time is a major barrier to accessing urban ecosystems globally

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Public access to nature is critical for human health and well-being. Ensuring that all urban residents live within a five-minute walk of urban ecosystems is a priority in towns and cities worldwide. We quantified the walking travel time to urban ecosystems for all urban residents, totalling more than 4.7 billion people. More than half of this population lives within a five-minute walk of an urban ecosystem, but there are gross geographic disparities in access, with the Global South disadvantaged. A sensitivity analysis highlighted a substantial improvement over previous analyses, which likely over- or under-estimated access due to methodological choices. Improving access to urban nature in the future will require innovative planning and design that creates new ecosystem spaces and improves walkability.

Access to urban ecosystems for recreation and exercise benefits the physical health and psychological well-being of urban residents[1–4]. International organisations, including the World Health Organization, United Nations, and OECD recognise that it is critical to ensure public access to urban ecosystems[5,6]. Notably, the United Nations Sustainable Development Goal (UN SDG) 11.7 aims to achieve universal and equitable access to "safe, inclusive, and accessible green and public spaces" by 2030[7]. To understand which people have access to urban ecosystems, we need detailed and systematic approaches for global quantification, which can be repeated periodically[8–10]. Previous efforts to quantify the current state of access to urban ecosystems globally have used geographic distance-based metrics to estimate accessibility rather than modelling the time it takes people to travel[8–10]. Previous work has also focused on vegetated urban ecosystems, thus excluding unvegetated ecosystem types which can provide important opportunities for recreation[8–10]. We developed improved indicators of urban ecosystem access by calculating walking times to a more nuanced and globally applicable definition of urban ecosystems. We quantified urban ecosystem accessibility for the 4.7 billion people who reside in urban areas with more than 50,000 residents globally. Our approach is globally systematic and can be repeated periodically[9–13], and we provide the resulting dataset for use in future research.

People face multiple barriers to accessing urban ecosystems[14]. A key barrier to accessing urban ecosystems is the travel time between a person's residence and the nearest urban ecosystem patch[15]. Longer travel times to the nearest urban ecosystem cost the person more economically[16], reduce their visitation frequency[15], and reduce health benefits[17,18]. Travel time is a crucial indicator for policy and planning because it can be influenced by a range of practical measures, including creation of urban ecosystems, investment in transport infrastructure, and improved provision of public transport services[19–21]. It is critical to quantify urban people's travel time to urban ecosystems globally as an indicator of success in achieving equitable access to urban ecosystems, and to highlight cities and neighbourhoods that are poorly provisioned[9,22].

Previous global analyses of access to urban ecosystems have measured the physical distances between populations and green spaces as an indicator of likely travel time, but have not modelled time explicitly[9,10,22]. Generally, a 300 m distance is equated to a five-minute walk, which is commonly used as an indicator of sufficient access. However, the time that it takes to travel between two locations the same distance apart varies in cities around the world depending on the terrain, travel network efficiency, and the density of other travellers[21,23,24]. Furthermore, walking speed can vary between individuals[25], with a 300 m distance representing a different travel time for different people.

The global science and policy discourse on public access to urban terrestrial ecosystems has focused predominately on "green" (i.e. vegetated) spaces[8–10,26–28]. This narrow interpretation of urban ecosystems is rooted in the context of the Global North, where most research has been conducted[29,30]. The focus on vegetated ecosystems disadvantages the many cities around the world where dense plants are not the dominant native land cover[31]. Bare or sparsely vegetated urban ecosystems including bare ground, desert, and ice can provide critical natural experiences and opportunities for physical activity[30,31]. Furthermore, the amalgamation of all vegetated ecosystems into one category can be disingenuous, since not all vegetated areas are equally accessible to the public[32,33]. In particular, croplands are typically inaccessible due to their private ownership and the presence of fences and other physical barriers to access, limiting their value for recreation[34].

This study aims to (1) provide a more accurate and nuanced understanding of global accessibility to urban ecosystems by explicitly modelling

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Table 1 | Models used in benchmark and sensitivity analyses

Model name	Approach	Urban ecosystem definition	Walking speed
Benchmark	Walking time	Vegetated + Bare	Population varying
E1	Walking time	Vegetated + Bare + Crop	Population varying
E2	Walking time	Vegetated	Population varying
U1	Walking time	Vegetated + Bare	Uniform
D1	Euclidean distance (300 m)	Vegetated + Bare	

walking time and integrating more pertinent definitions of urban ecosystem types for all urban residents globally, and (2) compare the sensitivity of the global assessment to methodological choices, namely (a) the definition of urban ecosystem spaces, (b) method of estimating travel time, and (c) explicit modelling walking time compared to Euclidean distance.

To provide a benchmark index of urban ecosystem accessibility that is comparable across cities[14], we modelled travel time directly by accounting for spatial variation in the ease of travel over space[24]. We combined this walking time model with high-resolution mapping of land cover[35] to quantify the minimum walking time to urban ecosystems for the 4.7 billion residents of all urban areas with a population of more than 50,000 people. We defined urban ecosystems to include bare and sparsely vegetated land covers alongside vegetation, including all tree, shrubland, grassland, bare or sparse vegetation, snow and ice, herbaceous wetland, mangrove, moss and lichen. Due to the limited public access in croplands, we excluded this land cover type[34]. Following previous recommendations for recreational space mapping, we included only patches of urban ecosystem of at least 1 ha in size[5,22], calculated across all land cover types combined. To account for some types of inter-population variation in walking time, we explicitly modelled average walking speed across age and sex groups[25].

To demonstrate the importance of how urban ecosystems are defined, interpersonal walking speed variability is modelled, and accessibility is measured, we compared the benchmark index estimates against sensitivity estimates described as four models (Table 1). We compared the outcomes from estimates made using two contrasting ecosystem definitions (vegetated ecosystems only, and vegetated, bare, and cropland cover), two assumptions regarding interpersonal walking speed variation (uniform walking speed and an age-sex- dependent variation) and using two accessibility measures (walking time estimation, and as defined by a 300 m Euclidean distance).

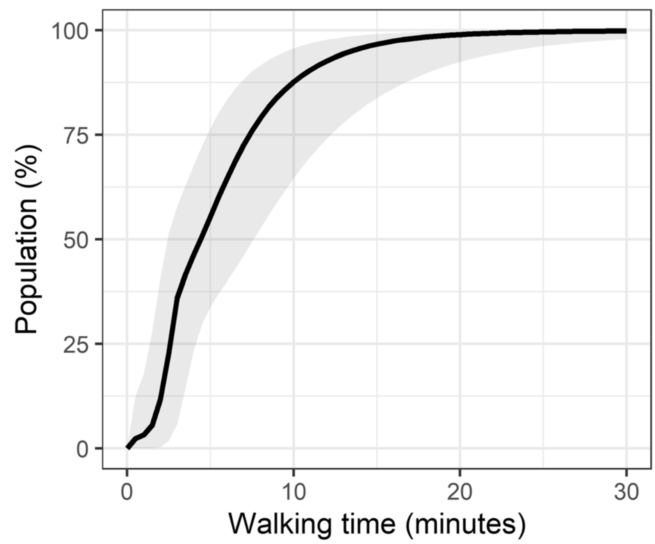

Fig. 1 | Cumulative distribution of the global urban population relative to walking time to urban ecosystems. Urban ecosystems are defined here including vegetated and bare land cover types but excluding croplands. Walking time estimated using population-varying walking speeds. Black solid line indicates median model estimates with shaded region denoting 95% confidence intervals.

Results

Walking time to urban ecosystems

Using the benchmark model, the mean walking time for an individual urban resident to access an ecosystem space was approximately 7.15 min (CI = 4.4–12.4 min), with more than half of the global urban population living within a five-minute walk (55.4%, CI = 33.8–76.5%; Fig. 1). Assuming that a five-minute travel time indicates sufficient access to ecosystem spaces, we must improve accessibility for between 23.5 and 66.2% of the world's urban population to achieve universal access. A notable 12.4% of the population, over 580 million people, must walk more than 10 min to access their nearest urban ecosystem space. There was substantial variation in walking time across the UN SDG regions, with 87.0% (CI = 67.1–95.4%) of those in Europe and North America living within a five-minute walk of an urban ecosystem space, compared to only 42.8% (CI = 23.1–72.5%) in Western Asia and Northern Africa (Fig. 2, Fig. 3). In total, 598 urban areas provided universal access within a five-minute walk, (CI = 12–2792 urban areas).

Methodological comparison

The sensitivity analysis highlights the importance of selecting the types of ground cover that are included in the definition of "urban ecosystems". Our benchmark model excluded croplands because these are commonly inaccessible to the public. When croplands were defined as accessible (Model E1), as in previous global studies[9,10], 64.4% (CI = 41.5–82.8%) of the population were within a five-minute walk of urban ecosystem. This over-estimated the number of people with access to urban ecosystem spaces by 8.9% of the global urban population (Fig. 4a, b). The inclusion of cropland had geographically biased impacts, particularly over-estimating access in south and east Asia, and western Africa (Fig. S1a). Our inclusion of bare and sparsely vegetated ecosystems provided a more positive estimate of global access to urban ecosystems than we would obtain using only vegetated ecosystem spaces (Model E2), for which 43.7% (CI = 25.0–67.6%) of the population live within a five minute walk (Fig. 4a, b; croplands excluded for comparability). Excluding bare and sparsely vegetated ecosystems under-estimated access to urban ecosystem spaces in the Sahara, Middle East and central Asia (Fig. S1b).

Our benchmark model incorporated variation in average walking speeds between age and sex categories. Using uniform average walking speeds for all population groups (Model U1) decreased the mean walking time to 6.9 min (CI = 4.7–10.1 min; Fig. 4a, c). Using uniform walking speed, the percentage of the global urban population living within a five-minute walk of urban ecosystems marginally increased, to 56.8% (CI = 40.7–74.0%). While the overall impact of including demographic variation in walking speed was relatively small, there was substantial regional variation, with urban areas with older populations in Japan, China, and Southern Europe being more sensitive to inclusion of this parameter (Fig. S2).

By explicitly modelling walking time, we obtained more conservative estimates of five-minute walking access to urban ecosystem spaces than using a 300 m distance threshold (Model D1; Fig. 4a). The 300 m Euclidean distance method consistently over-estimated access to urban ecosystem

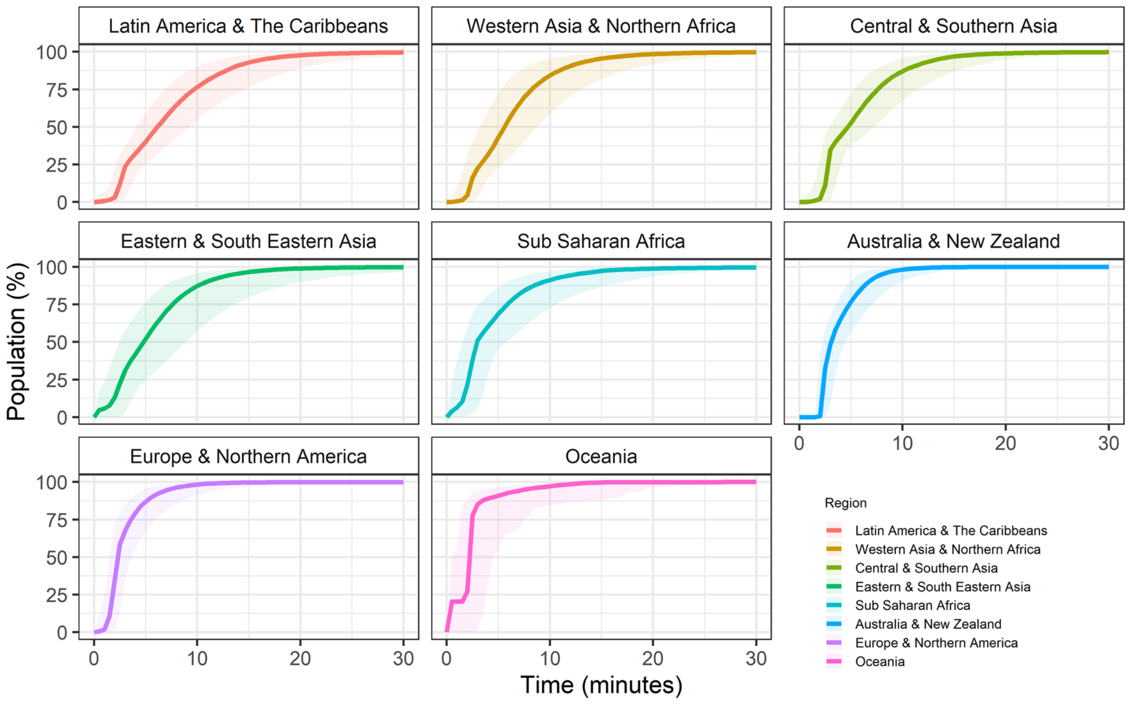

Fig. 2 | UN SDG regional variation in cumulative distribution of the population relative to walking time to urban ecosystems. Each UN SDG region shown on separate sub-plot as labelled and according to colour legend. Solid lines indicate median estimates. Shaded regions indicate 95% confidence intervals.

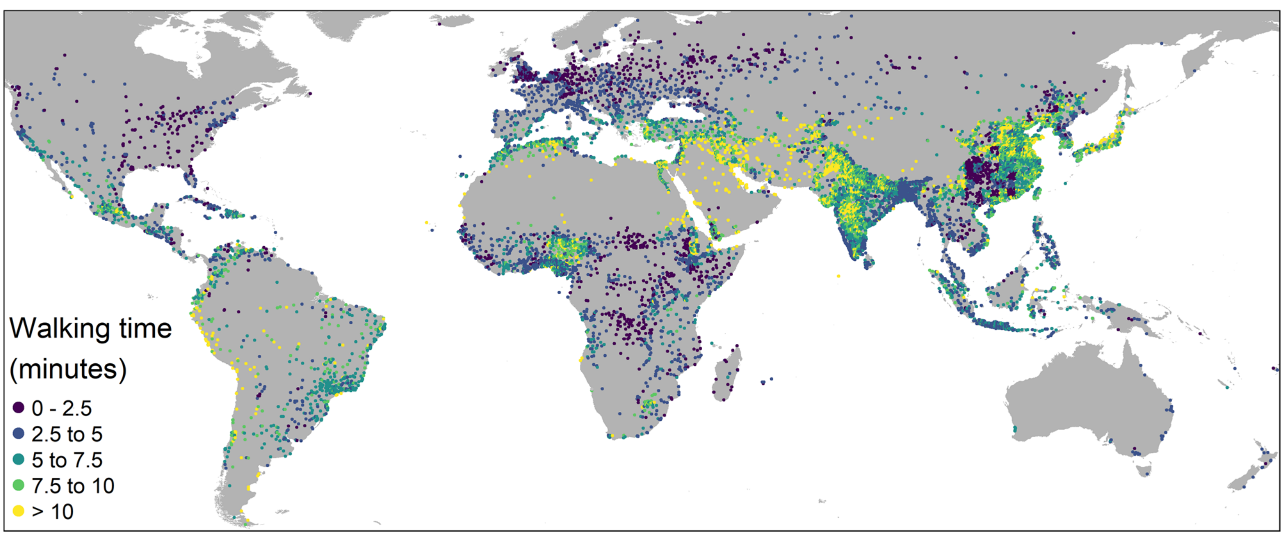

Fig. 3 | Population-weighted mean walking time to urban ecosystems. Median simulated estimates for each urban area. Global map excludes some urban areas in remote regions. Estimated using population-varying walking speeds and assuming a definition of urban ecosystems as vegetated and bare ecosystems, excluding cropland.

spaces and showed a non-linear relationship with the five-minute walking time (Fig. S3a–c). The proportion of people living within a five-minute walk was more similar to the proportion living within a 300 m distance at low and high proportions, and these estimates diverged most at intermediate levels (Fig. S3a–c). As a result of this nonlinear mismatch, regions with lower urban ecosystem accessibility in India, northern China, and Nigeria showed a larger overestimate if using the Euclidean distance method (Fig. S4).

Discussion

Our study highlights that almost half of the global urban population must walk for more than five minutes to access urban ecosystem spaces. By quantifying accessibility on a global scale, we demonstrate that achieving universal access to urban ecosystems by 2030 will require substantial improvements in urban ecosystem provision and mobility support systems to bridge this accessibility shortfall.

If residents do not have convenient walking access to urban ecosystems, they are less likely to use these spaces for recreation, exercise, and relaxation[15,16]. Consequently, residents are less likely to benefit from the physical and health benefits conveyed by activity in ecosystems[17,18]. A lack of convenient access to ecosystems may also have deeper consequences for the relationship between people and the environment, contributing to the extinction of natural experiences documented among many urban dwellers[36,37]. Natural experiences are critical for environmental education and contribute to personal motivations to protect wildlife and engage in environmentally conscious behaviours such as recycling and energy conservation[37,38]. Low access to urban ecosystems may thus have substantial

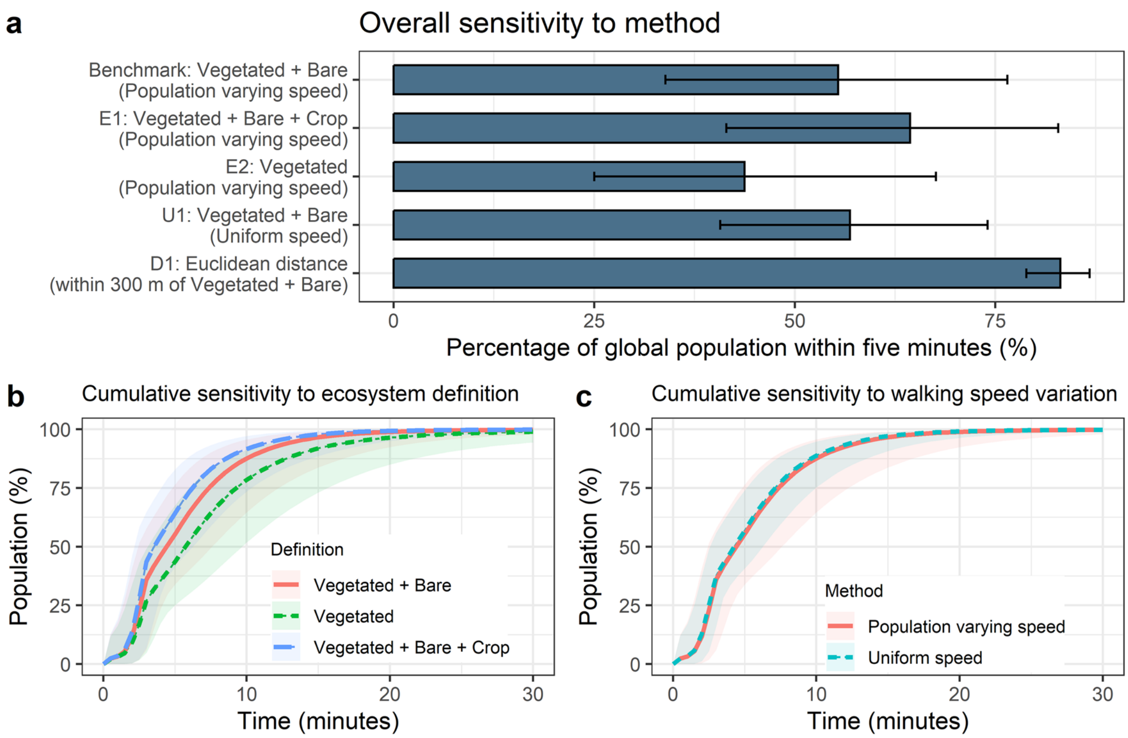

Fig. 4 | Sensitivity analyses of estimated walking time to urban ecosystems. **a** Sensitivity of estimated global population within five-minute walk of an urban ecosystem to methodological choices regarding estimation method, definition of ecosystems, and incorporation of population walking speed variability. Model names given in Table 1. Cumulative distribution of global urban population according to walking time to urban ecosystems in sensitivity analyses of **b** urban ecosystem definition. Red solid line indicates benchmark model, green dashed line indicates model E2, blue dashed line indicates model E1. Cumulative distribution according to **c** method to estimate population walking speed variability. Red solid line indicates model benchmark model, blue dashed line indicates model U1.

society-wide implications for future environmental stewardship at a global scale[38].

Walking time to urban ecosystems was inequitable across the UN SDG regions, with the Global North providing the best accessibility to residents (Fig. 2). The greater access to nature in more economically developed urban areas is likely to result from a combination of several factors, including their generally lower population densities and greater ecosystem coverage[10,39]. The lower walking time to urban ecosystem spaces is consistent with other access advantages experienced by the residents of Global North cities, such as better public transport provision, greater private vehicle ownership, and fewer thermally uncomfortable days[40–42].

The UN SDG regions with the longest walking times to urban ecosystems were Latin America and the Caribbean, and Western Asia and Northern Africa. These regions are characterised by dense population centres, often surrounded by croplands, which we excluded from our definition of urban ecosystems due to their typically private ownership and access. The longer walking times to urban ecosystems experienced by many residents of these regions is likely to be compounded by other barriers to access, including poorer public transport provision, thermally uncomfortable daytime conditions, and in some cases risks of conflict, terrorism, or other interpersonal violence[40–42].

Many urban residents may live within a five-minute journey of an urban ecosystem if travelling by vehicle. However, vehicular travel is not ideal for travelling short distances in cities, due to the need to find parking facilities in close proximity of the destination. The need to use a vehicle also presents additional cost and inconvenience barriers to accessing ecosystems, which is why walking accessibility remains the gold standard target[5,6]. Furthermore, many urban residents do not have access to private or public vehicle use, particularly in less economically developed regions[40,41]. To ensure equitable access to urban ecosystems, we thus emphasise the importance of improving walkable access rather than relying on vehicular travel.

This research shows that the methodological approach chosen to quantify accessibility substantially impacts the estimates. By explicitly modelling travel time rather than relying on distance thresholds, we provide more conservative estimates that better capture the reality of walking accessibility. Our findings suggest that previous distance-based approaches have likely overestimated the global state of accessibility to ecosystems[9,10,22]. Furthermore, our study emphasises the importance of defining urban ecosystems. Moving away from a narrow interpretation of vegetated ecosystems rooted in the Global North, our metric included a more diverse range of urban ecosystems worldwide, including bare and sparsely vegetated areas[30,31], and excluded croplands due to their typical inaccessibility. A shift in thinking towards more nuanced and ecologically and socially relevant definitions of urban ecosystems is essential for informing future urban planning efforts and promoting equitable access to nature for urban residents in all biomes.

Reducing average walking time to urban ecosystems can be achieved by creating new urban ecosystems in under-provisioned areas, and investing in pedestrian transport infrastructure such as dedicated pathways and traffic crossings[19–21]. In addition, access for pedestrians can be enhanced by improving the availability of public transport infrastructure[19–21]. Wherever possible, we recommend that improving walkable access is prioritised over public and private vehicular transport, although improving public transport also has additional benefits for urban connectivity and greenhouse gas emissions reductions[43]. Design interventions at smaller scales, such as creating new parks, can enhance accessibility by providing urban ecosystems closer to people's homes[19]. Adding larger patches of urban ecosystems is challenging, as available space is typically constrained, the cost of urban land is high[22]. Opportunities to retrofit larger patches of urban ecosystems may be found in post-industrial redevelopment projects, or managed retreats from areas at high environmental risk, such as flood zones[22,39].

Future research should continue to refine accessibility models to better quantify urban ecosystem availability and access. Our approach excluded cropland ecosystems on the basis that they are typically not accessible to the general public, yet some croplands are used by the public, and some grasslands or forests in the peri-urban zone are inaccessible - for example, when fenced for pastoral agriculture. More detailed spatial datasets that describe land ownership and barriers to accessibility would help to improve our knowledge of the provision of urban ecosystems for recreation. At present, land ownership and access maps are available for only a few cities, and there are no systematic global datasets available for this purpose[44,45].

In this study, we treated all patches of the urban ecosystem as equivalent in value for recreation and exercise. However, larger patches of native ecosystems can provide a richer recreational experience due to their enhanced biodiversity[46] and give greater benefits for health and well-being[47,48]. To provide a more nuanced insight into the extent to which urban people have access to nature, we must quantify accessibility to different types of urban ecosystems. Urban vegetation is diverse and typically contains many exotic plant species[49]. At present, there are no global maps of native vegetation within urban areas. In the future, it may be possible to map more detailed categories of urban vegetation by leveraging more detailed remote sensing of vegetation classes, or large global datasets of plant occurrence records[50].

Our incorporation of population variability in average walking speed used mean and 95% confidence interval values for sub-groups, defined by age and sex. These values provide some estimate of variability in walking speed between people and are suitable for quantifying average accessibility across urban areas and globally. However, our approach did not incorporate critical aspects relevant for equity, such as the walking speed of people living with physical and mental health constraints[51,52]. In the future, existing data on average travel speeds for those living with reduced walking speeds or reliance on wheelchairs could be used to conduct modified accessibility metrics[52], although information on micro-scale topographic and physical barriers to each urban ecosystem would be required[53].

The modelled walking time was highly sensitive to the definition of publicly accessible ecosystems (Fig. 4b). For the benchmark model, we assumed that all croplands were inaccessible, because they are commonly privately owned and fenced[34]. However, croplands can contain active footpaths and are used for recreation in the surroundings of some urban areas[54]. Similarly, although the benchmark model considered all grasslands and forests as accessible, they may not be, for example, in the case of some peri-urban production forest plantations or private sports facilities[55,56]. To improve the accuracy of assessing publicly accessible urban ecosystems, it will be necessary to map accessibility independently from land cover, rather than inferring it. Currently, there are no consistent global maps of urban public open space or land ownership, but it may be possible to scale up approaches that have used citizen science mapping data[55], or information on actual visitation derived from social media or mobile phone datasets[56].

To move towards improved indicators of urban ecosystem accessibility, it will be necessary to integrate metrics describing separate barriers to access. In combination with walking time, these metrics must include additional barriers[14], such as the availability of public or private vehicular transport[57], individual health and mobility challenges[58], financial costs of recreation and the availability of time to spend on recreation[17,59,60], concerns about crime, violence, or dangerous wildlife[61,62], and the thermal comfort of ecosystem spaces[63]. These additional barriers to access have been analysed in specific cities, but they have not been compared across all urban areas globally[14,64–66]. To integrate across multiple barriers to access will require future work to resolve differences in the units used across indicators, perhaps by using travel time as the common metric.

This study has focused on quantifying access to relatively large outdoor patches of ecosystems, but exposure to smaller ecosystems such as roadside trees, private gardens, individual pot plants, and vertical greenery can also benefit mental and physical health[67–69]. To gain a more holistic understanding of urban ecosystems and health, it will be critical to understand global variation in access to these other ecosystem types, to further estimate the relative benefits of different types of urban nature exposure, to different people[70]. Mapping the location and accessibility of small urban ecosystems globally is challenging with current technology, but it may be possible to leverage ground-level imagery in regions where these exist[71]. Alternatively, private gardens can be mapped by comparing very high-resolution satellite or aerial images with municipal land ownership maps[44].

This is the first study to quantify travel time to urban ecosystems for all urban residents globally. The world remains a long way from providing universal access to urban nature. Achieving equitable access to urban ecosystems is a multifaceted challenge that requires coordinated efforts across urban planning, transportation, and public health sectors. Our findings provide a comprehensive understanding of current global walking access patterns and highlight the need for targeted interventions to bridge the identified accessibility gap, ensuring that all urban residents can benefit from the vital ecosystem services provided by these spaces. Future research should continue to refine accessibility models and explore innovative solutions to overcome both physical and socio-economic barriers to urban green space access. Further comparisons of walking accessibility within and between cities will provide insights into disparities and will be crucial for developing more effective urban planning strategies and policies.

Methods

Spatial datasets

We used a globally consistent database of urban centres and population data to define the study extent[72,73]. The urban centres dataset was defined based on urban agglomerations with more than 50,000 people in 2020[73]. Within each urban centre, we characterised the spatial distribution of people at a ~100 m by ~100 m pixel resolution[72,74]. We characterised the spatial distribution of ecosystems within each urban centre using a global ~10 m by ~10 m pixel resolution land cover dataset dating from 2020[35]. As residents can travel outside the boundaries of their urban centre to access ecosystems, we used a second land cover dataset dating from 2019 to characterise the spatial distribution of ecosystems within a 30 km buffer surrounding each urban centre boundary[75]. The land cover dataset used to map ecosystems in the areas adjacent to the urban centres was of a lower resolution (~100 m by ~100 m)[75]. The lower resolution land cover dataset was used in the areas surrounding each urban area to reduce the total amount of high resolution data that was required to be downloaded and processed.

We mapped three types of urban ecosystem patches within each urban centre by extracting different land cover classes and measuring the contiguous patch area (Table S1). Mapping of ecosystem patches in the area surrounding each urban centre used comparable land cover classes (Table S1). The higher resolution map of urban ecosystem patch presence within the urban centre was resampled to match the lower resolution of ~100 m by ~100 m, thus mapping the pixels that contained a patch of urban ecosystem.

Walking time modelling

Pedestrian walking time was modelled using a global friction surface with ~930 m by ~930 m pixel resolution dating from 2019[21,24]. This global dataset was developed using a cost-distance approach, accounting for average walking speeds and variation with slope and presence of roads and broad land use type (urban, rural)[21,23,24]. The dataset has been used in several studies modelling global walking accessibility[21,23,24], including in cases relevant to short journeys in urban settings[21]. We resampled the friction surfaces to match the ~100 m by ~100 m resolution of the ecosystem patch presence map using a nearest-neighbour algorithm[76], and calculated the minimum walking time from pixels of each type of urban ecosystem. Walking time was modelled as the cumulative cost-distance between pixels based on the travel distance and underlying friction surfaces, using the costDist function from the terra package for the R language[76].

To assign walking times to each resident person, we resampled the travel time layers to match the projection of the global population dataset[74] using a nearest-neighbour algorithm[76]. The cost-distance algorithm modelled walking time between each pixel and the most accessible pixel containing an ecosystem patch, but did not account for travel within patches containing an ecosystem patch. To modify the cost-distance walking time, we thus made the conservative assumption that people were required to travel the maximum possible distance within a pixel to reach its contained ecosystem patch. The walking time within the pixel containing the ecosystem patch was quantified as the friction coefficient (measured in minutes per m travelled) multiplied by the distance between two opposite corners of the pixel. The distance between two opposite corners of the pixel was estimated, assuming a square pixel, as the side length multiplied by the square root of 2. The side length of each pixel was estimated as the square root of the area.

For all pixels that did not contain an ecosystem patch, the cost-distance algorithm modelled the walking time from the edge of the most accessible patch to the centre point of the pixel. Given that a person living within a pixel may live within a shorter or longer walking time than from the centre point, we made the conservative assumption that all residents were required to travel an additional distance equivalent to half of the distance between two opposite corners of the pixel.

Uncertainty propagation for walking time

There is considerable uncertainty in the walking time as modelled using the cost-distance method, and this uncertainty varies spatially and has been quantified as part of the friction dataset creation[23]. While previous work has reported the modelled travel time estimates and errors separately[21,24], we applied a Monte Carlo simulation approach to estimate and generate 95% confidence intervals for error-adjusted travel times. In previous work, travel times for a grid of two degree by two degree grid cells were estimated using the cost-distance method were compared against an independent estimate from Google Maps[23]. For multiple journeys within each grid cell, the mean and standard deviation in the percentage error between the cost-distance and Google Maps method were reported[23]. We extracted the mean and standard deviations of the percentage error for each urban centre, from the grid cell that it was located within, or the nearest grid cell with data available. For each of 10,000 Monte Carlo replicates, we used these mean and standard deviation values to simulate the error-adjusted travel time, assuming that the percentage error in walking time was a normally distributed random variable. The median, 2.5 percentile, and 97.5 percentile of the 10,000 estimates for each urban area were used as the error-adjusted estimate of walking time, lower and upper 95% confidence intervals, respectively. These error-adjusted walking times were propagated through the analysis.

Individual variation in walking time

People walk at different speeds, with average walking speed varying substantially across demographic sub-groups[25]. To account for variation in walking speed between age-sex sub-groups in each urban area, we used data provided by a meta-analysis of 41 studies from around the world, which incorporated measured walking speeds from 23,111 people[25]. For each of 16 sex-age sub-groups, we extracted information on the overall average walking speed, and the upper and lower 95% confidence intervals. We converted each of these values to a proportional multiplier of the assumed standard walking speed used in the friction data layers, which is 1.4 m per second[23,24]. We used these multipliers to modify the walking speeds of the population of each age-sex sub-group in each city, based on spatial data describing the age and sex structure in 2020[77]. To quantify the age and sex structure of each urban area, we extracted the total population within each category from grid cells that overlapped with the urban area boundary. We applied the age and sex structure for each urban area uniformly within its boundaries. For uncertainty propagation involving individual variation in walking tim,e we applied the lower 95% confidence interval of walking speed to the upper 95% confidence interval of walking time, and vice versa.

Sensitivity analysis and comparison

We conducted a sensitivity analysis to compare the impacts of the key methodological decisions described above. To investigate sensitivity to of how urban ecosystems are defined, we compared estimates made using three ecosystem definitions. Our benchmark definition incorporated all vegetated and bare ecosystems, but excluded cropland. For sensitivity analysis we compared an inclusive definition of vegetated, bare, and cropland land covers (Model E1), and a definition of vegetated ecosystems excluding cropland (Model E2). The full list of land cover types included in each definition can be found in Table S1. The benchmark model included population age-sex group variation in average walking speed. To investigate sensitivity to how interpersonal walking speed variability is modelled, we compared the results using a uniform walking speed (Model U1). To provide a comparison between the benchmark explicit modelling of walking time developed in this study, and previous urban green space accessibility indicators, we also defined the population living within a five-minute walk of urban ecosystems as those within a 300 m Euclidean distance[9,10,22] (Model D1).

Data availability

All datasets resulting from the analyses, and required to run the analyses, are provided in the following institutional repository; https://datastore.landcareresearch.co.nz/dataset/walking-time-to-urban-ecosystems (https://doi.org/10.7931/266q-1s18).

Code availability

All code required to repeat the analyses are provided in the following institutional repository; https://datastore.landcareresearch.co.nz/dataset/walking-time-to-urban-ecosystems. (https://doi.org/10.7931/266q-1s18). The repository also includes required datasets and code to obtain the required public datasets.

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Author contributions

D.R. coordinated the study and performed the data processing and analyses. D.R., M.S., and R.N.B, conceptualized the work, proposed, drafted, and reviewed the content of the article.

Competing interests

The authors declare no competing interests.

Additional information

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