Article

Global disparities in urban green space use during the COVID-19 pandemic from a systematic review
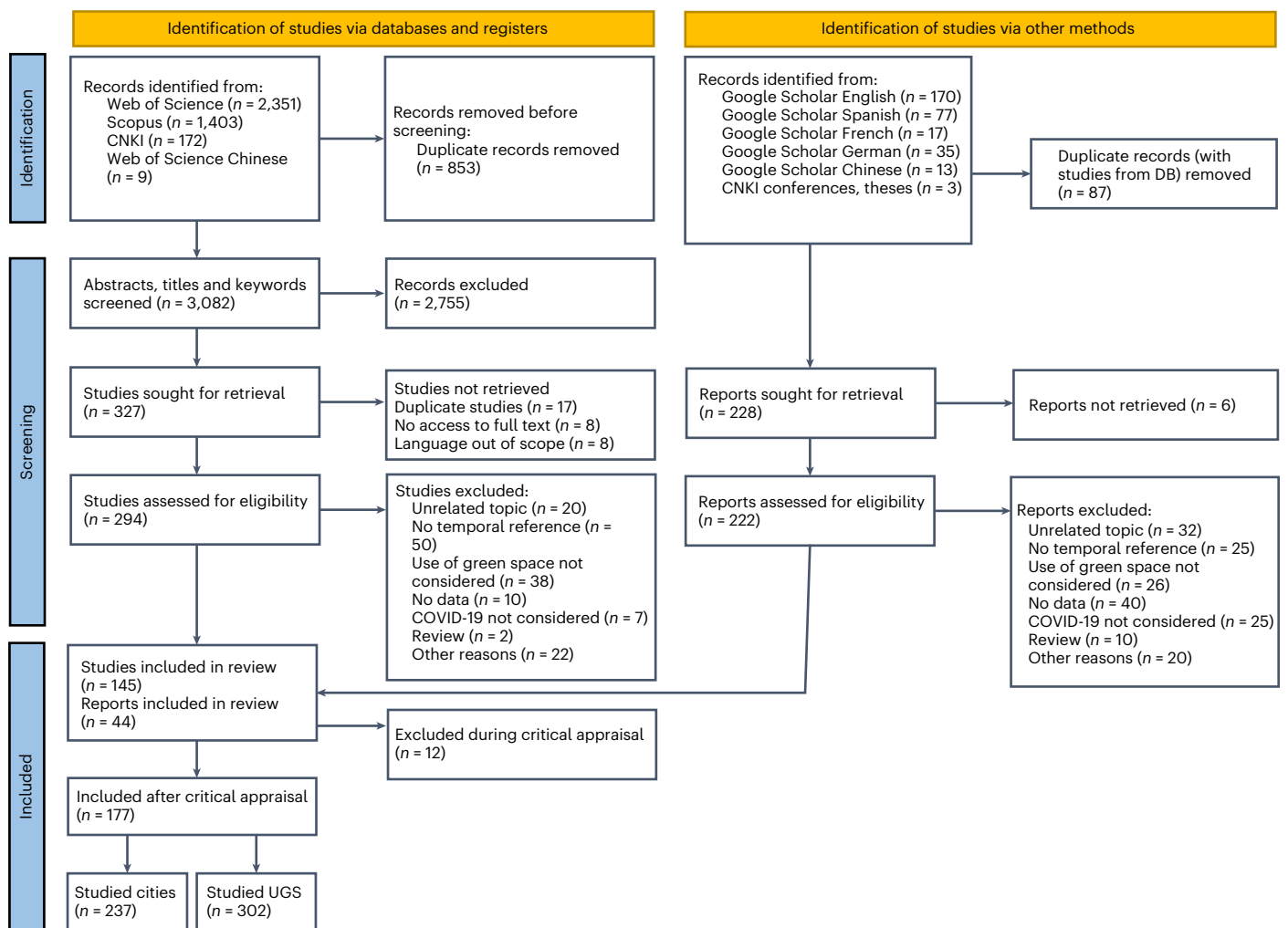
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The COVID-19 pandemic disrupted urban resilience and challenged the use of urban green space (UGS). Previous studies lack consensus on whether UGS use increased or decreased during and after lockdowns and how this related to policy, economic conditions and UGS types. In a systematic review, we screened >3,000 articles in 5 languages, identifying 177 articles on UGS use changes in 60 countries. The cities studied show diverging changes in UGS use. Generally, decreases occurred where COVID-19 policies were stricter and the gross domestic product per capita was lower, including in most of the few studied areas of the Global South. All studies on private gardens and 60% on forests and other natural areas showed increases, while 77% of studies conducted on public parks indicated decreased use. The global disparity in UGS use was exacerbated during the COVID-19 pandemic, demonstrating the need to enhance green infrastructure for healthy cities and to extend it beyond public parks.

By 2050, the global urban population is projected to grow by 2.2 billion people[1], posing a challenge to creating green, healthy and resilient cities. While there is growing recognition that being outdoors benefits the physical and mental health of urban people[2–4], green spaces within and near cities are often under increasing pressure due to densification and accelerating urban growth. The unequal distribution of urban green spaces (UGS) within cities raises concerns about environmental inequity, as less privileged people often have less access to UGS[5–7]. The COVID-19 pandemic (henceforth 'COVID-19') has highlighted the importance of UGS to mitigate social and health challenges[8,9]. Understanding the demand for various types of UGS in times of crisis is essential to improving quality and access to urban green infrastructure and supports setting priorities for different types of private and public land. Thus, lessons from COVID-19 can help make cities fit for future crises that may result from climate change or other pandemics[10–12].

Numerous local studies on UGS use during COVID-19 have revealed multidirectional changes, leading to elevated discussions about the importance of UGS[13]. Many studies reported that COVID-19 has profoundly impacted the use of green spaces in cities worldwide, with evidence for both decreased use during lockdowns[14,15] and increased use during and afterwards[16–18]. However, it remains unclear whether these changes were consistent across different world regions, user groups and types of public and private green space. In parallel, access to green spaces varies widely for different groups of the population at a local scale—for example in relation to socio-economic status[19]—and is highly unequally distributed between cities in the Global North and the Global South[20]. The gross domestic product (GDP) per capita is a widely used indicator for per capita income at subnational scales[21] and has been shown to correlate with UGS availability in contexts outside COVID-19 (ref. 22). We thus expected GDP per capita to be related to UGS use during or after lockdowns. Furthermore, the policy responses

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Identification of studies via databases and registers

Identification

Records identified from:
Web of Science (*n* = 2,351)
Scopus (*n* = 1,403)
CNKI (*n* = 172)
Web of Science Chinese
(*n* = 9)

Records removed before
screening:
Duplicate records removed
(*n* = 853)

Screening

Abstracts, titles and keywords
screened (*n* = 3,082)

Records excluded
(*n* = 2,755)

Studies sought for retrieval
(*n* = 327)

Studies not retrieved
Duplicate studies (*n* = 17)
No access to full text (*n* = 8)
Language out of scope (*n* = 8)

Studies assessed for eligibility
(*n* = 294)

Studies excluded:
Unrelated topic (*n* = 20)
No temporal reference (*n* = 50)
Use of green space not considered (*n* = 38)
No data (*n* = 10)
COVID-19 not considered (*n* = 7)
Review (*n* = 2)
Other reasons (*n* = 22)

Included

Studies included in review
(*n* = 145)
Reports included in review
(*n* = 44)

Excluded during critical appraisal
(*n* = 12)

Included after critical appraisal
(*n* = 177)

Studied cities
(*n* = 237)

Studied UGS
(*n* = 302)

Identification of studies via other methods

Records identified from:
Google Scholar English (*n* = 170)
Google Scholar Spanish (*n* = 77)
Google Scholar French (*n* = 17)
Google Scholar German (*n* = 35)
Google Scholar Chinese (*n* = 13)
CNKI conferences, theses (*n* = 3)

Duplicate records (with
studies from DB) removed
(*n* = 87)

Reports sought for retrieval
(*n* = 228)

Reports not retrieved (*n* = 6)

Reports assessed for eligibility
(*n* = 222)

Reports excluded:
Unrelated topic (*n* = 32)
No temporal reference (*n* = 25)
Use of green space not considered (*n* = 26)
No data (*n* = 40)
COVID-19 not considered (*n* = 25)
Review (*n* = 10)
Other reasons (*n* = 20)

Fig. 1 | Flowchart of the systematic review process. PRISMA diagram[62] illustrating the identification of relevant articles used for the analyses separated by searches in databases and registers (DB) and other methods such as Google Scholar.

to contain the spread of COVID-19 strongly varied at a global scale, including lockdowns in many, but not all, countries. The different containment and closure policies have been measured with a so-called stringency index, based on indicators such as school closures, movement restrictions and travel bans[23]. While decreasing use with increasing COVID-19 policy stringency can be anticipated for some UGS, such as parks in urban centers, it remains unclear how the experience of lockdowns changed use within a broad range of UGS over time in relation to before COVID-19.

Previous reviews on green space use during COVID-19 have partially addressed these questions but were limited by their selected studies to a narrative review[24] and an incomplete evidence base during the ongoing publication of primary studies[25]. A comprehensive understanding of UGS use during times of pressure, related COVID-19 policy and economic conditions and their regional variations is still lacking. In that sense, it is especially important to specify the outcomes of those studies that refer to a change in uses, including a data-driven assessment of at least two points of time. Considering the increased space requirements due to higher overall demand and the need for physical distancing, decision-makers must re-evaluate how much green space a city needs[26,27]. Our results will thus provide evidence for urban green planning, including a broad range of formal and informal UGS, benefiting both future pandemic preparedness and the general well-being of urban dwellers.

Here we report results of a systematic review on the global evidence for changes in UGS use during different phases of COVID-19, specified for major green space types and different global regions. We elucidate how the differing stringency of restrictive measures and GDP per capita affect changes in UGS use globally. We further assess equity aspects in accessibility and adaptation strategies of different groups of people to derive implications for enabling UGS in future city development. We included articles in Chinese, English, French, German and Spanish to capture studies of broad geographic coverage. We also considered studies from diverse disciplines using a multitude of methods such as qualitative reports, quantitative surveys, big data assessments from social media and GPS tracking while critically appraising study validity.

We define UGS as areas covered with vegetation or water that lie within, are intersected by or are directly tangential to the borders of settlements of any size, from villages to megacities. This includes public green spaces such as parks and urban forests, informal or unplanned green spaces such as vacant areas and vegetated street sides, and semi-private and private areas such as allotments, home gardens and balconies that support the self-organized use of UGS. Change in UGS use refers to an increase or decrease in the combined frequency and duration of any leisure or work-related activity in UGS. Based on these definitions, we investigate the effect of COVID-19 on the use of UGS as outlined in a pre-published protocol[28]. We address the following
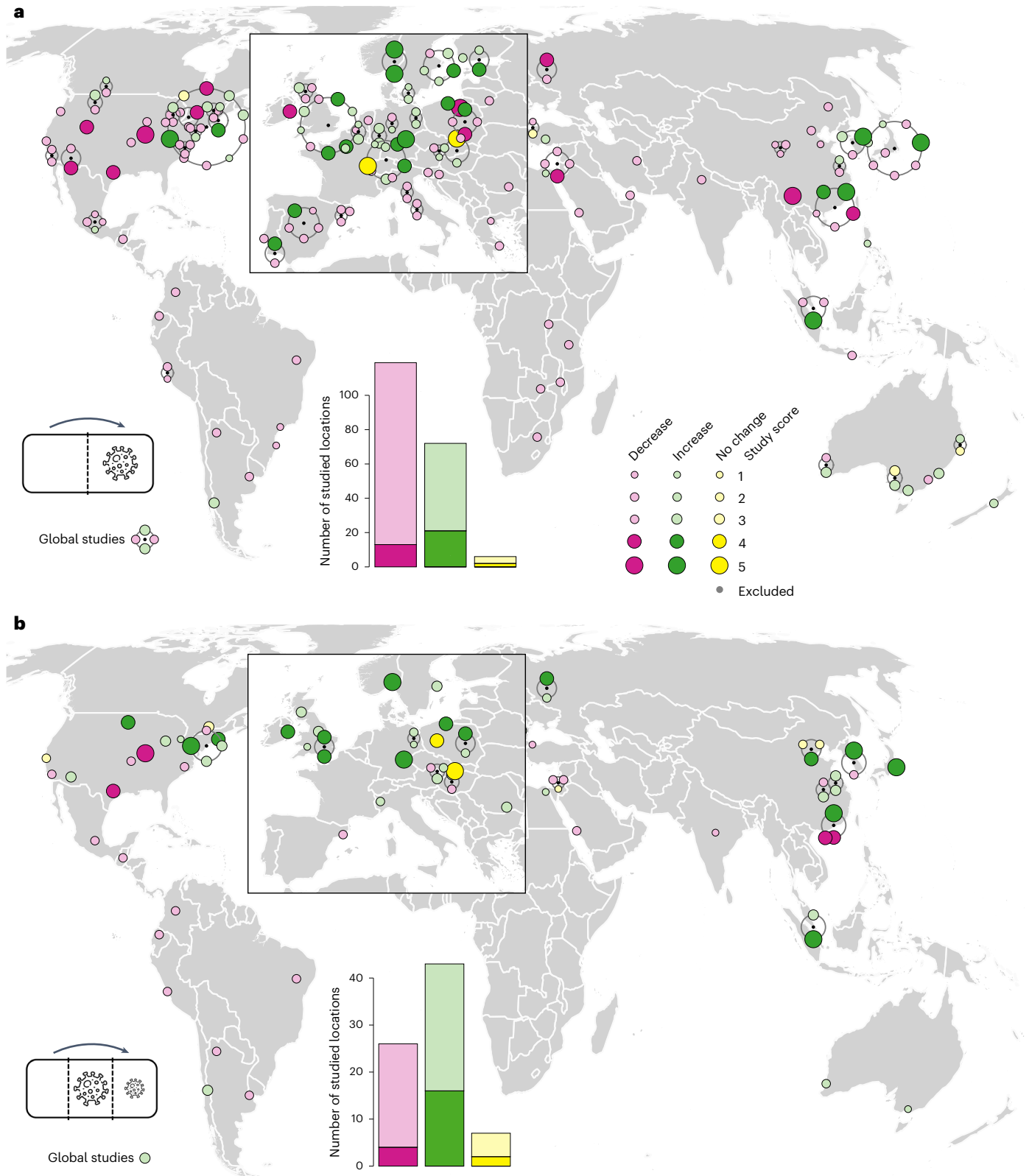
Fig. 2 | Overview of UGS use in studied cities. a, Changes from before to during first lockdowns. **b**, Changes from before to after first lockdowns (indicated by respective virus icons). Data points are color-coded by reported outcomes (*n* = 237) with each colored point indicating one studied city. Points in the bottom left of a and b (Global studies) report results for multiple locations together. Increasing symbol size and color saturation indicate increasing study validity score based on ratings from the critical appraisal of quantitative methods. Europe is magnified due to the high study density; no studies were found in North and West Africa, which is therefore covered. Data points arranged on circles around small black dots show studied cities in overlapping locations at the depicted scale. Basemap from Natural Earth (https://www.naturalearthdata.com). Credit: virus icons, Flaticon.com.
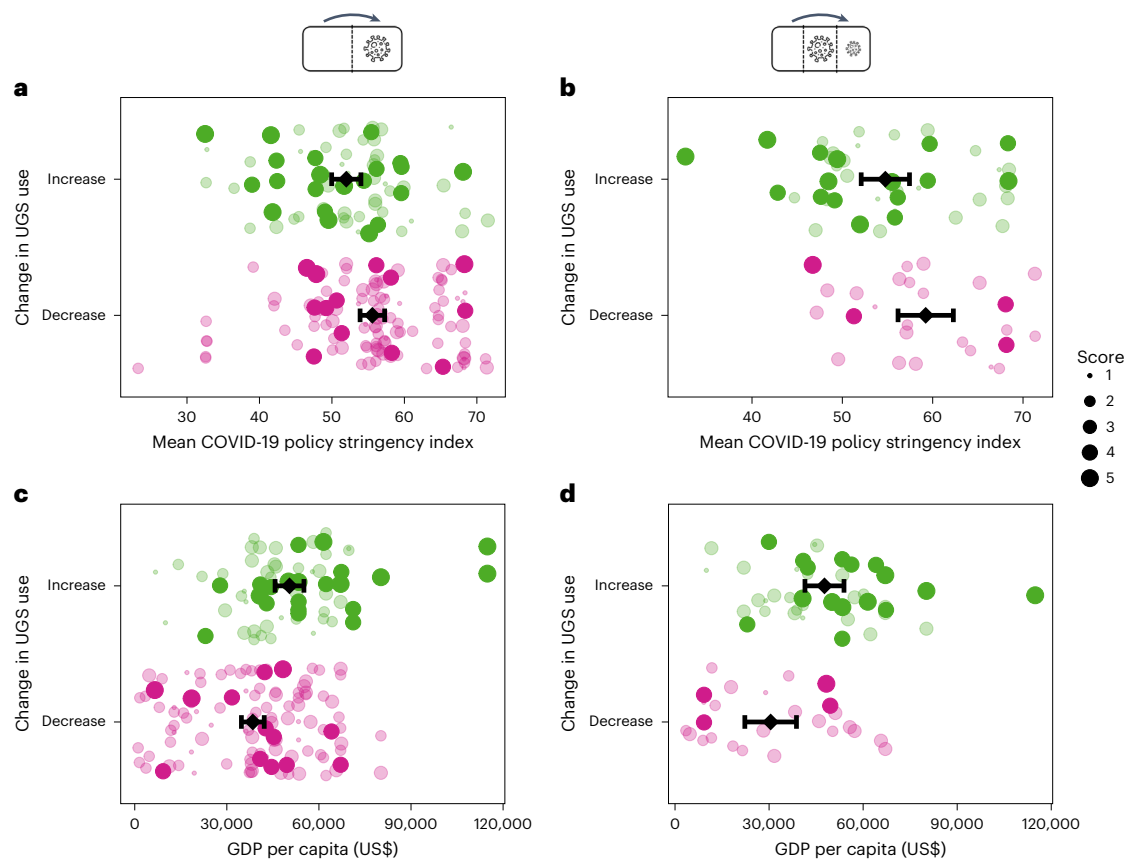
Fig. 3 | Changes in UGS use in context of COVID-19 policy and GDP. a–d, Jitter plots with one dot for each studied city with means (black diamonds) and 95% confidence intervals (error bars) depending on the mean stringency of COVID-19 policies in 2020 (ref. 23) (**a,b**) and GDP per capita in 2015 (ref. 21) (**c,d**). **a,c**, Data for before–during lockdowns (n = 191). **b,d**, Data for during–after lockdowns (n = 69). The sizes and color saturation of the data points indicate the study validity score. Credit: virus icons, Flaticon.com.

questions: (1) How did UGS use change globally and what is the geographic coverage of available studies? (2) How does the change in UGS use relate to a COVID-19 policy stringency index[23] and to GDP per capita? (3) How do changes in use relate to equity in UGS accessibility and different adaptation strategies? (4) How do changes in UGS relate to different types of UGS?

Results

Systematic review outcomes

Out of 3,310 articles initially screened, we included 189 in the review (Fig. 1 and Supplementary Table 1) following inclusion criteria in an a priori published protocol[28]. We excluded 12 articles due to unclear descriptions of the study question and/or methods. From the remaining 177 articles, we extracted data for a total of 237 cities, which we used for further analyses. These cities were distributed across 60 countries, with 18% in the United States, 10% in China and 5% each in Australia, Germany, Poland and the United Kingdom (Supplementary Fig. 3). Out of the 237 studied locations, 223 were described in English, seven in Chinese, five in German and one each in Spanish and French. For the comparison of UGS types, we further differentiated articles that provided results for different UGS types within the same city, resulting in a total of 302 studied UGS.

We critically appraised all studies for their internal validity (that is, methodological strength, separated by qualitative and quantitative criteria). For the 237 studied cities worldwide, a high number (80%) received low and medium validity scores (1–3), while 20% received scores of 4 or 5, indicating high validity, and hence reliability, of the study findings. The latter studies included control data from before

COVID-19 and considered confounding variables such as weather conditions in the analysis (Supplementary Fig. 4).

Global changes in UGS use and geographical coverage

During the first COVID-19 lockdowns, cities included in the reviewed studies were divided into those where the use of UGS increased and those where it decreased compared with before COVID-19 (before-during lockdowns): 60% of locations reported decreased UGS use, spread across all continents. In contrast, 37% of locations showed increased use and 3% remained unchanged. The areas with increased or unchanged uses were concentrated in Central and Northern Europe, with additional cases in North America, East and Southeast Asia, Australia, New Zealand and Chile (Fig. 2). Comparing UGS use before and after the first lockdowns (before-after lockdowns), 34% of the studied locations showed decreased UGS use, while 57% showed increases and 9% no change. Studies from Europe, East Asia and Australia mostly indicated increased UGS use, while North and South America showed a more mixed picture. The majority of studies originated from Europe, Australia and North America, with an additional concentration in East Asia (China, Japan and South Korea). In contrast, few relevant studies were identified in this review from Africa, South and Central Asia, and Latin America.

COVID-19 policy stringency and GDP per capita

The stringency of COVID-19 policies had a negative impact on UGS use during and after the first lockdowns (Fig. 3a). A weighted logistic regression, considering the quantitative study validity score, revealed that locations reporting decreased use had significantly higher
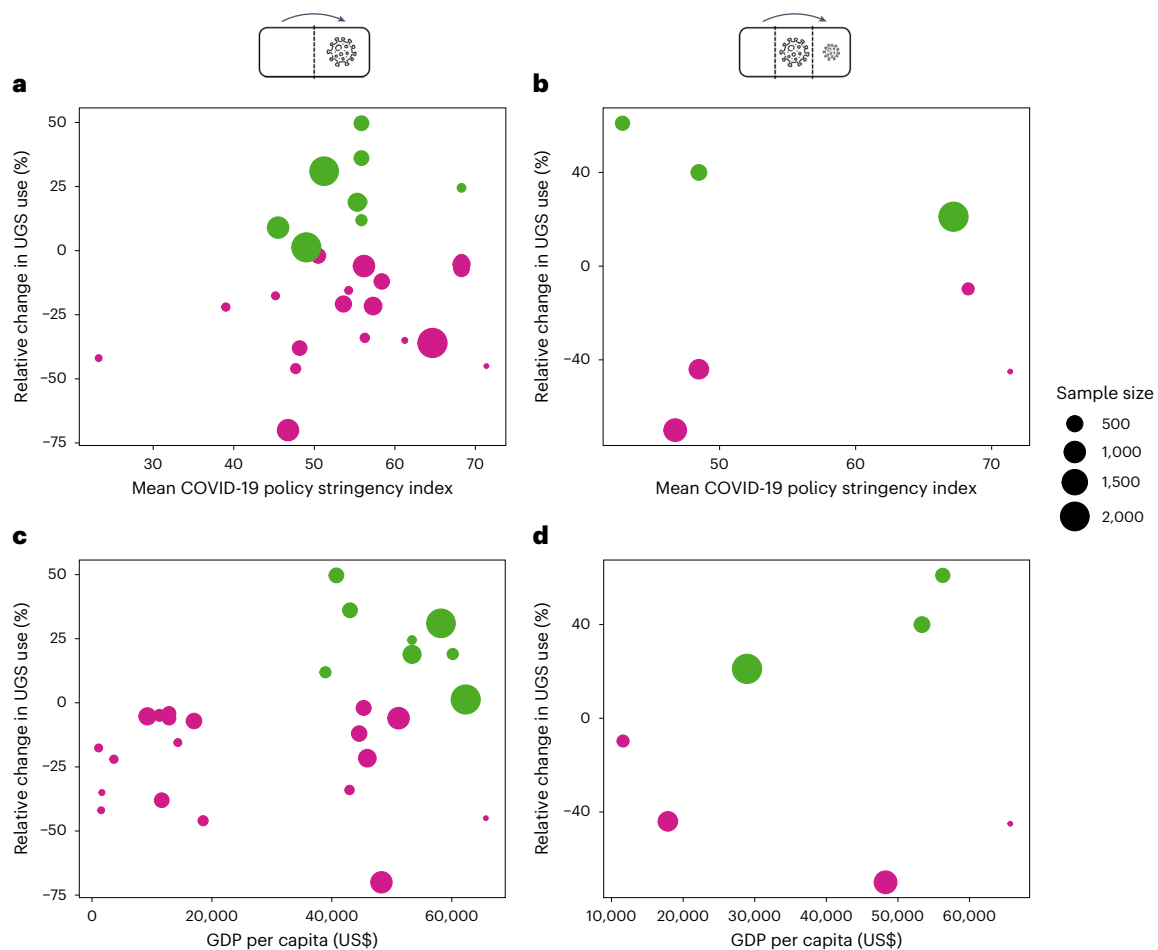
Fig. 4 | Magnitudes of change in UGS use. a–d, Relative change in % based on a subset of studies providing such information plotted against mean strictness of COVID-19 measures in 2020 (**a**,**b**)[23] and GDP per capita in 2015 (ref. [21]) (**c**,**d**). The sizes of the data points indicate sample size. **a**,**c**, Changes before–during lockdowns (*n* = 30). **b**,**d**, Changes before–after lockdowns (*n* = 7). Credit: virus icons, Flaticon.com.

COVID-19 governance stringency in 2020 than those with increased use before-during lockdowns (*P* < 0.001, full summary provided in Supplementary Table 1). However, this difference is not significant (*P* = 0.129) when considering the subset of studies with high validity (that is, with a score >3). A similar analysis for changes before-after lockdowns also showed significantly higher governance stringency for locations with decreased use (*P* < 0.001). Again, this trend was not confirmed in the subset of high-validity studies, where only 3 out of 23 locations showed increases in green space use, making a meaningful statistical test challenging. The 95% confidence intervals for these comparisons overlapped (Fig. 3a,b) and so do not confirm the difference from the logistic regression.

The GDP per capita of studied locations also played a role in the direction of changes in UGS use: locations with higher GDP per capita were more likely to experience an increase in UGS use than locations with a lower GDP per capita (Fig. 3). The logistic regression indicated significantly higher GDP per capita in locations with reported increased UGS use before-during lockdowns (*P* < 0.001). This difference was still significant in the subset of studies with high validity (*P* = 0.028), despite a correlation between study score and GDP per capita. For changes before-after lockdowns, GDP per capita was significantly higher in locations with increased UGS use (*P* < 0.001). These trends were confirmed by the non-overlapping 95% confidence intervals (Fig. 3c,d), aligning with the results from the logistic regression.

In a subset of 36 studies that conducted quantitative surveys on relative changes in UGS use, average reported changes ranged from

+50% to −95% before-during lockdowns and from +61% to −70% before-after lockdowns (Fig. 4). It is worth noting that studies based on other methods such as social media and GPS tracking reported even higher increases in UGS use of 291% (ref. [18]) during and 240% (ref. [29]) after lockdowns. There were few studies with large sample sizes from countries with lower GDP per capita and overall, inconsistent measures and reporting across studies, as well as raw data, make statistical analysis challenging. However, visual interpretation suggests that GDP per capita may be related to UGS use, with stronger decreases in UGS use observed in areas with lower GDP and greater increases in areas with higher GDP (Fig. 4c). No clear visual pattern between relative changes in UGS use and strictness of COVID-19 policies was evident (Fig. 4a,b).

Equity in UGS accessibility and qualitative differences in UGS use
The use of UGS during COVID-19 changed in multiple ways that were influenced by equity in UGS accessibility (Fig. 5a) and individual avoidance, adaptation and compensation strategies of urban dwellers (Fig. 5b). The main reported equity issues were that people with lower incomes and higher social vulnerabilities (partly related to migration history and racial disparities), as well as in some cases women and older people, faced greater obstacles to accessing UGS compared with other parts of society. Changes in the way people used UGS were mostly reported in terms of frequency and duration of UGS visits. People also adapted to the situation through changes in group composition, activity types, timing of visitation, distance and types of visited

	Theme	Description	Example countries with references
a Equity			
	Wealth	Lower-income individuals had less access to UGS compared with higher-income groups who had more opportunities for nature experiences. Gated residential areas led to segregated access.	Mexico, the UK and the USA[58, 62, 63]
	Ethnicity	Non-white individuals in communities with higher social vulnerability used UGS less due to limited access.	The USA[48, 64]
	Gender	Gender disparities exacerbated as women felt more vulnerable and anxious, affecting their access to and safety concerns in UGS.	Mexico[62]
	Migration history	Individuals born in Scandinavia and the Baltics had a greater likelihood of living in a greener area compared with those born in other regions.	Sweden[65]
	Age	Elderly people faced challenges in accessibility to UGS and decreased visitation due to fear of infection.	Australia, Denmark and Norway[29, 66, 67]
b Avoidance, adaptation and compensation			
	Change in frequency	The number of visits to UGS was higher (or lower) compared with before COVID-19.	Israel, Japan and Singapore[17, 68, 69]
	Change in duration	The periods of time spent in UGS were longer (or shorter) than before COVID-19.	China, Israel and the UK[70, 71, 72]
	Change in group composition	Reduced group sizes due to risk of infection. New groups using UGS, as previously indoor activities shifted outdoors during COVID-19.	Palestine, Spain and the USA[73, 74, 75]
	Change in activity type	Shift to new uses of UGS due to compensation for lack of indoor activities.	Australia, Canada and Italy[33, 76, 77]
	Change in timing of visitation	Shift in days of the week and visitation times to avoid crowding and due to flexibility of home-office situation.	China, Germany and the UK[36, 78, 79]
	Change in travel distance	Increased use of UGS closer to home, but also of UGS outside city centers due to closures or to avoid crowds.	Italy, Canada and Finland[33, 54, 77]
	Change in UGS type	Shift from urban parks to other types of UGS, especially private gardens, due to closures and risk of infection. Increased use of previously less visited public forests, natural areas and watersides.	The USA, Poland and Germany[46, 55, 80]
	Divergent behaviors	While certain groups of people reduced or stopped using UGS, others continued at even higher frequencies.	China, Germany and Switzerland[39, 70, 81]

Fig. 5 | Qualitative aspects of change in UGS use during COVID-19. a, Equity issues in accessibility and changed uses. **b**, Avoidance, adaptation and compensation behaviours. (For original quotes and references see Supplementary Tables 4 and 5). Data in this figure are from refs. 17,29,33,36,39,46,47,54,55,58,76–94. Credit: icons, Flaticon.com.

UGS. Some studies also reported divergent behaviors, where some user groups reduced or stopped their outdoor activities, while others increased visits to UGS.

Types of UGS

A comparison of UGS use before-during lockdowns revealed clear patterns among different types of UGS. Specifically, private gardens, UGS near homes, forests and natural areas showed a high proportion of increased or unchanged use (100%, 78% and 71%, respectively), whereas public and historic parks had a high share of studies reporting decreased use (71% and 100%, respectively; Fig. 6a). Community gardens and other public agriculture initiatives showed contrasting trends in this period. In the comparison before-after lockdowns, decreased uses were still recorded at a lower share in unspecified UGS types and public parks (54% and 30%, respectively; Fig. 6b). Private and public gardens, forest and natural areas, as well as UGS near homes, primarily showed cases of increased use or no change before-after lockdowns (100%, 100%, 100% and 86%, respectively). The significant difference between use of UGS types was confirmed by a weighted X^2 test, considering study validity score ($P < 0.001$ for before–during lockdowns and $P = 0.015$ for before–after).

Discussion

The extensive body of literature on UGS use that has emerged since the COVID-19 pandemic in 2020 provides unprecedented evidence from diverse geographies. There was significant variation in the changes in UGS use, partly within the same countries or even cities and under similar policy stringencies. We associate these diverging results with differences in: (1) UGS availability and accessibility to different groups of people; (2) adaptation strategies of people; and (3) the use of different UGS types. Overall, our findings indicate that during COVID-19, regions with higher GDP per capita experienced increased
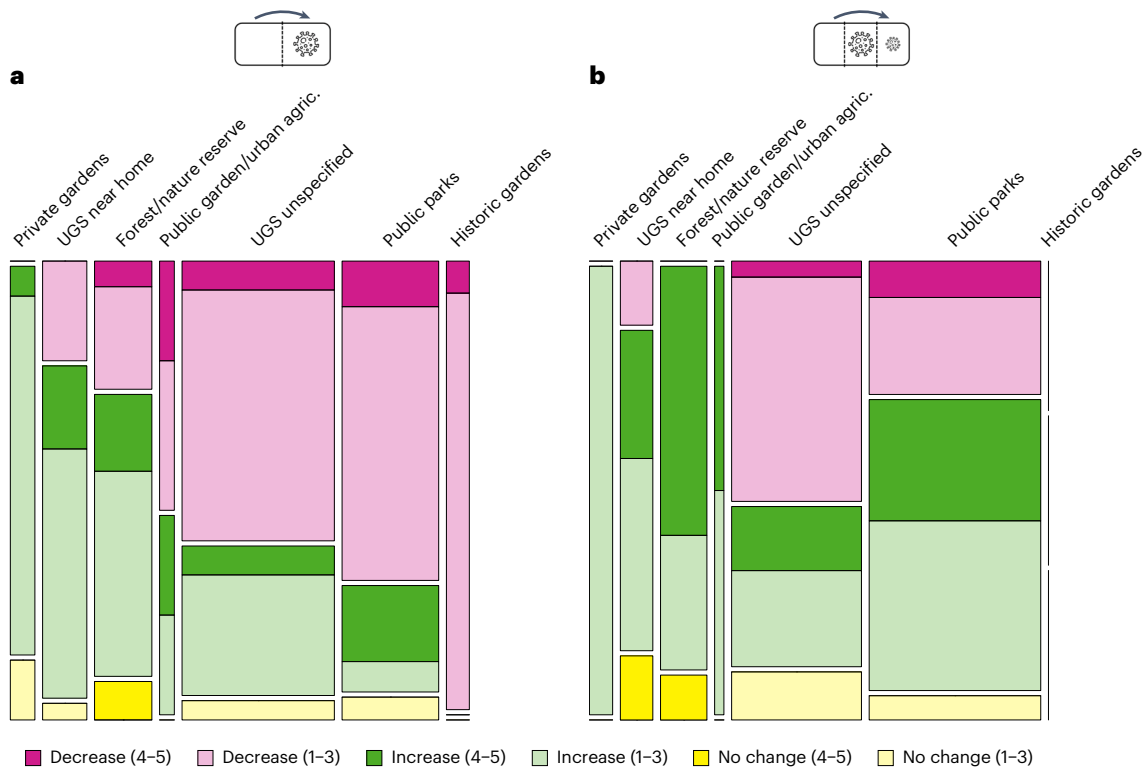
Fig. 6 | Mosaic plots summarizing studied UGS types by their reported change in use. a,b, Reported change in use before-during (**a**) and before-after lockdowns (**b**) (*n* = 302). Agric., agriculture. Colors indicate decreased (pink), increased (green) or unchanged (yellow) use of UGS. The study validity score is visualized using lighter (low study validity) and brighter (high study validity) colors and the numbers in parentheses (1–3 represents low validity scores and 4–5 high validity scores). The graphs allow both a quantitative comparison (the widths of the boxes are determined by the number of cases) and a relative comparison (on the *y* axis). Credit: virus icons, Flaticon.com.

use of UGS, potentially bolstering the resilience of their urban populations to COVID-19, given the known importance of exposure to UGS for human health[3]. In contrast, many other regions reported decreased UGS use, possibly due to a scarcity of available UGS, which might even have exacerbated the physical and psychological challenges faced by urban populations during COVID-19 (refs. 30–32). Urban parks in particular showed a wider decrease in use compared with forests and natural areas, underscoring the importance of these near-natural spaces in providing opportunities for movement and recreation in challenging times. The increased pressure on UGS reported in the analysed COVID-19 studies and the previously shown overall unequal distribution and accessibility of UGS[20] underline the urgent need to give UGS a more prominent role in urban planning and management decision-making.

Impact of COVID-19 policies and adaptation of UGS use
UGS use decreased more frequently in areas with stricter COVID-19 policies, including park closures, curfews and restrictions on movement for social distancing[33,34]. However, this impact of policy measures was not confirmed across a subset of survey-based studies that reported magnitudes of change, indicating that COVID-19 governance was not the only factor that affected UGS use. While overall more locations reported decreases, some places experienced substantial increases in UGS use, even during lockdown periods. For example, Oslo, Norway, saw outdoor activities surge by 291% when permitted, indicating that people sought UGS to compensate for other restricted activities[18].

One important aspect of the changed UGS use during COVID-19 was adaptation and avoidance strategies, particularly in crowded public parks. People modified their UGS visit patterns by changing the frequency, duration, timing, group composition, types of activities and travel distance. For instance, a social media analysis in

London, United Kingdom, showed a shift in park visits from weekends to weekdays[35]. In Germany, families coordinated schedules to use community gardens to avoid overlaps[36]. In Tel Aviv, Israel, people tended to visit UGS more often with a domestic partner than in groups[37]. In Brazil, elderly residents reported traveling longer distances to find uncrowded places for physical activity[38]. Individual behaviors in response to COVID-19 restrictions differed strongly—for example, fewer people overall visited peri-urban forest areas of Switzerland, but those who did came more frequently[39].

After the easing or lifting of restrictions, UGS use increased in many places, possibly due to a compensation effect, replacing other activities[40]. While travel limitations and recommended work-from-home practices continued well into 2022, UGS recreation was one of the few safe activities during the evolving COVID-19 situation.

GDP and other disparities in UGS access during COVID-19
The geographic distribution of UGS use patterns reveals a North–South divide, both globally and within Europe. The Global North consistently shows higher UGS use compared with the Global South. These findings align with the overall availability and access to UGS, which varies greatly between North and South[20]. Yet, it is important to note that the overall evidence on UGS use is unequally distributed, with a greater number of studies with high validity and studied locations covered in the Global North. For instance, Africa is represented by only one study based on an online survey[41] and many of the Latin American locations are also covered by only one article reporting results of multiple locations based on Google Mobility data[42].

In addition to the global disparities, our results also show a clear correlation between higher GDP per capita and increased UGS use. Economic wealth, as indicated by GDP, is related to the level of public and private investment in UGS planning and maintenance[43].

Consequently, regions with limited resources to invest in UGS may not have been able to provide sufficient and good quality UGS to meet the increased demand during COVID-19. Moreover, cultural and other behavioral differences in different geographies may also underlie the observed variations in UGS use[15,44].

Apart from the global differences, there are strong local disparities in UGS use and availability within countries and cities. COVID-19 further accentuated these existing inequalities, impacting the health and well-being of individuals with different income levels[45]. For example, a study in the United States[46] found that in the states of New York and California, access to nature decreased overall, particularly for female, non-white and low-income respondents. Similarly, research in North Carolina[47] showed a general decrease in park use, with a more pronounced reduction in socially vulnerable communities. Given that these vulnerable communities already had lower access before COVID-19, it potentially exacerbated existing disparities in UGS use and environmental equity[48].

Importance of different types of UGS during COVID-19

Our results highlight significant differences in the utilization of different types of UGS. Private gardens saw a notable increase in interest[49] and use, providing substantial well-being benefits for garden owners both in the Global North[50,51] and the Global South[52]. We also found increased UGS use near residential areas, probably due to movement restrictions that limited outdoor activities to short distances or time periods[53–55].

Forests and natural areas, including watersides and vacant land, experienced predominantly increased uses. These less managed areas, often parts of greenbelts or located in urban fringes, played a crucial role in urban green infrastructure during COVID-19. Community gardens and urban agriculture projects faced more challenges due to COVID-19 regulations than private gardens but gained even more popularity after the end of strict lockdowns. They proved to be of critical importance for marginalized communities[56,57].

On the other hand, public parks, primarily designed for recreation, experienced more decreases in use during strict lockdowns than other types of UGS. Parks in central urban locations in particular faced the risk of crowding during COVID-19, leading to potential viral transmission concerns[58]. Consequently, parks all over the world were temporarily closed or voluntarily avoided by the public due to fear of infection[9,59,60].

Strengths and limitations of the review

This study represents a comprehensive global overview of changes in UGS uses during COVID-19 based on a high number of study locations. To do so, we included studies of varying methodological strength, showing a higher share of increased use cases reported in studies with high validity than in studies in lower validity. This inclusive approach extended the geographic reach of insights into UGS use to less studied areas. Our review shows contradictions in the globally reported findings on changed UGS use, sometimes even within the same region. These discrepancies may be attributed to differences in governance strictness and social disparities, and possibly to variations in study validity. We included studies that employed multiple methods in the review, including qualitative and quantitative assessments, which made detailed meta-analyses and quantitative comparisons challenging given the different types of data, reporting standards, sampling sizes and units. In particular, many studies relied on data with strong limitations, such as Google mobility reports, which use a very generic definition of 'park', leading to results differing from all other methods. Even more generic are results based on Google Trends search interest[9,49] that we excluded during article screening as these only represent peoples' intentions to use UGS, which may not correspond to their actual behavior. Overall, the analysed studies concluded at a point when COVID-19 was not yet over. It remains unclear whether UGS use will remain elevated in the long run. This is probably situation-dependent and can only be analysed a few years from now.

Conclusions

COVID-19 raised critical questions about land systems and equity[61]. In the urban context, the lessons learned from COVID-19 provide a framework to address other timely challenges in urban development, such as increasing environmental equity in cities, adapting to climate change and enhancing urban contributions to biodiversity conservation.

Our study emphasizes the importance of different types of UGS in times of pressure, as indicated by their prevailing increase in use. Given the ongoing competition between green, blue and gray infrastructure development in cities, our insights offer essential recommendations for the future development of livable and equitable cities, including: (1) increasing the provision of small domestic gardens or community gardens near housing, including on rooftops, and recognizing the importance of existing gardens; (2) capitalizing on unexploited opportunities of informal UGS near housing that exist in many cities (for example, on vacant land, along transportation corridors) and facilitating safe access to them; and (3) preserving and restoring forests and natural areas within and at the edge of cities, while providing access to urban residents.

These lessons from COVID-19 strongly support approaches that make cities greener, healthier and more resilient in the face of current and future challenges—ultimately benefitting urban residents.

Methods

This review adheres to the guidelines of the Collaboration for Environmental Evidence (CEE) (https://environmentalevidence.org/) and is reported following the PRISMA reporting standards[62]. Following CEE guidelines, we published an a priori protocol[28] that was reviewed by two external experts on systematic review methodology and on the content subject. The PRISMA 2020 Reporting Checklist is provided in Supplementary Data 2.

Question components

We defined question components using the following PECO (Population, Exposure, Comparators, Outcomes) terms:

- Population: human population globally living in urbanized areas that had lockdowns or similar restrictions during COVID-19
- Exposure: use of green spaces
- Comparators: before versus during and after lockdowns
- Outcome: changes in use, behavior and perception of green space

Search strategy

Sources. We conducted a comprehensive search for publications in five languages (Chinese, English, German, French and Spanish) to reduce bias and ensure a wide geographical coverage of potential studies[28]. We included both peer-reviewed papers and gray literature defined here as publicly available, non-commercially published literature. We conducted the following bibliographic searches using institutional subscription of the ETH Zürich: (1) the Web of Science (see Supplementary Table 1 for a full list of databases); (2) Scopus; and (3) CNKI (www.cnki.net). In addition to the bibliographic searches, we conducted searches in Google Scholar. We used 'private' mode to conduct the searches to prevent the influence of previous browsing history and location on search results.

We searched the Web of Science and Google Scholar to identify publications in all languages. We further searched Scopus in English using the same search string as for the Web of Science and CNKI in Chinese. The search was restricted to articles published after 1 January 2020. The initial searches were carried out on 13 June 2022 and search alerts were set until 27 August 2022. We provide full details of the searches in Supplementary Tables 1 and 2.

Search string. Together with native speakers and after series of initial scoping searches, we defined sets of keywords composed by (1) type of settlement, (2) type of the green space, (3) COVID-19 related terms

and (4) different use terms. The search string was developed in English and subsequently translated into other languages. We improved the list of English search terms with the R package litsearchr[63]. During this procedure, all abstracts, titles and keywords from the first 1,000 hits in the Web of Science were text-mined to generate a list of frequently mentioned keywords, sorted by strength. From the resulting list of terms, we identified seven that we added to the initial search string for improvement. The final search string (5) combines the different search terms for each element (1–4) using Boolean operator AND. Search string (4) was left out from the searches in languages other than English as only few studies were available and they were not captured with such a specific search string. The asterisk (*) was a wild-card character that represented any group of characters, including no character. Quotation marks were used to search exact phrases.

To test the comprehensiveness of the search strategy, we pre-selected a list of 20 papers[28] that we considered to be key to the subject and that cover different subject domains and regions of interest. We extended the set of English keywords until all 20 papers were included in a search of the Web of Science.

The final search string used was the following (in Web of Science format, TS = topic search):

(1) TS = (urban* OR town* OR settlement* OR "populated area*" OR agglomeration* OR "built environment*" OR city OR cities OR village* OR "public space*")

(2) TS = (green* OR park* OR "open space*" OR "natur* area*" OR "urban natur*" OR garden* OR forest* OR vegetate* OR ecosystem* OR backyard* OR cemeter* OR graveyard* OR waterside* OR river* OR "roof garden*" OR balcon* OR "vertical green*" OR agricultur* OR "protected area*" OR "nature reserve*" OR "national park*")

(3) TS = (pandemic* OR COVID OR COVID-19 OR corona* OR coronavirus OR SARS-COV-2 OR lockdown* OR "social distancing" OR "Severe Acute Respiratory Syndrome Coronavirus 2" OR "2019-nCoV")

(4) TS = (use OR need* OR benefit* OR recreation* OR health OR service* OR motivation* OR mobility OR attitude* OR leisure OR walk* OR hike OR hiking OR running OR play* OR window* OR view* OR gardening OR jogging OR sport* OR "physical activity" OR outdoor*)

(5) TS = (1) AND (2) AND (3) AND (4)

Screening

In the screening process, we applied predefined eligibility criteria in two stages: first, title and abstracts, and then screening full-text articles. Each article was independently screened by two reviewers. The disagreement rate was 3% at the title/ abstract stage and 5% at the full-text stage. All disagreements were resolved through discussion or consultation with a third person. The eligibility criteria were developed based on the PECO components and studies that fulfilled all of the following criteria were included:

- They were conducted in a country affected by COVID-19
- They looked at the change in use of UGS
- They had a reference to the time before and during or after lockdowns.
- They included actual or stated uses of UGS or other evidence that directly related to the use of UGS
- They had quantitative or qualitative data on the outcomes
- They were written in English, Chinese, German, Spanish or French

Articles that did not fulfill the eligibility criteria were excluded. The following types of article were also excluded: (1) reviews, (2) studies based on anecdotal evidence and (3) studies where changes in the use of UGS since COVID-19 were assumed as a given (no data linked with the change).

Gray literature was also screened in two stages: first based on titles and a short excerpt from Google Scholar, then by assessing the full text. All other screening steps were conducted with the online tool Rayyan[64]. We report all reviewing steps with article numbers

in a PRISMA diagram (Fig. 1)[62]. A list of articles excluded at the full-text stage and the reason for exclusion are provided in the Supplementary Information.

Critical appraisal

To assess the internal validity of the studies we employed a six-point (0–5) Likert-scale rating system[28]. Two independent reviewers conducted the critical appraisal for all studies that were included after full-text screening. Studies that did not include clearly stated research questions and a clear description of the methods used were excluded as these were knock-out criteria.

We assigned points on the basis of specific criteria to rate the validity of the studies. The criteria for quantitative results (that is decrease, increase or no change in UGS use) included: (1) sampling methods appropriate for the research question, such as the number of observations and geographical distribution; (2) adequacy of statistical analysis for the research question, with clear descriptions and data fit for model; (3) inclusion of control cases referring to the time before COVID-19 as a baseline for comparison; (4) consideration of confounding variables, such as the temporal distribution of observations and weather conditions, that could impact the results; (5) inclusion and proper handling of confounding variables in the data analysis. Studies that did not meet at least criterion 1 received 0 points and were subsequently excluded from the review, making this de facto a knock-out criterion. Qualitative studies were appraised on the basis of the above-mentioned criteria on sampling methods and also on four concepts of rigor or trustworthiness within qualitative research[65]: (1) transparency of the research process and decision taken; (2) credibility of the findings and their interpretation by the researcher; (3) reflexivity, such as reflecting on limitations and potential influence researcher may have had on the results; and (4) transferability (that is, to what extent are the results are generalizable to other contexts).

The results of the critical appraisal are included in the table of included studies in the Supplementary Information.

We also assessed the external validity of the included studies from their geographical location, type of green space and socio-economic setting. These contextual factors are considered in the Results and Discussion to provide a contextual evaluation of the study findings.

Data extraction

After screening, we extracted predefined variables from the selected studies to Excel. At the beginning of the data extraction process, we jointly extracted data from five articles, after that, one person continued the extraction and throughout the process discussed unclear cases with a second person. In a second round, a third person independently checked all references and the previously extracted data again. For articles reporting on multiple locations and types of green spaces, data were extracted separately for each city (location) and UGS type (study). We extracted the relevant data from the text, tables and graphs. In cases where only graphs were available, we used an online tool (www.graphreader.com) to extract numerical data for analysis.

For each study, we extracted information on geographic location (city name and country), reference period (before/during/after first lockdown), type of UGS studied (categorized into seven categories), methodology used (categorized into six categories), sample size, study period, percentage of change in UGS use and proportion of people that increased/decreased/did not change UGS use, as well as a qualitative expression of increase/decrease/no change in frequency or duration of UGS use (or a combination of both) with regards to the reference period. As different countries and cities implemented varying measures to combat COVID-19, we defined the reference period as being before, during or after the most restrictive government-imposed measures (lockdowns) in the first phase of COVID-19 in 2020. The measures reported in the studies ranged from movement restrictions[66] to strict curfews[67–69]. We based the classification of whether a

study referred to the time during or after the first lockdowns on the descriptions provided in the papers. Given that we only analysed papers published between 2020 and 2022, we did not have information on the total duration of COVID-19, and it was thus not feasible to classify papers according to a longer timeline. Therefore, the common reference point among the papers was the outbreak of COVID-19 in early 2020 with the first lockdowns, compared with later phases. A table of all included studies with metadata and extracted data is provided in the Supplementary Information.

For a qualitative analysis of accessibility and changed UGS uses, we extracted data that reported more complex or nuanced changes that extended beyond the frequency and duration of UGS use. We coded the data according to the most prevalent issues, which were adapted from the predefined data extraction categories outlined in the review protocol: (1) equity in UGS use and accessibility, with differences regarding wealth, ethnicity, gender, migration history and age; (2) avoidance, adaptation and compensation strategies, which besides changes in frequency and duration were changes in group composition, activity type, timing of visitation, travel distance and UGS type, as well as divergent behaviors within the same population. We briefly summarized the main issues in Fig. 5. The full set of data and respective references are provided in Supplementary Tables 4 and 5).

Contextual variables

We considered several potential effect modifiers from a set predefined in the protocol[28] to further analyse their impacts on the changes in UGS use. These modifiers included strictness of COVID-19 policies, regional economic situation (indicated by GDP per capita) and type of green space. Some other potential modifiers defined in the protocol, such as the location of UGS in the urban fabric, were not consistently reported in the analysed literature, which limited our ability to make comparisons across studies. For the same reason, we also did not consider individual effect modifiers of study participants such as gender, age, ethnicity and so on unless they were presented in the studies as part of equity issues.

To determine the stringency of COVID-19 policy measures, we relied on the stringency index from the Oxford COVID-19 Government Response Tracker[23]. This index is a composite measure of COVID-19-related policies including school and workplace closures, curfews and travel bans, rescaled to a value from 0 to 100. Given that all studies in our review referred to changes during and after the lockdowns in the first phase of COVID-19 in 2020, we calculated the average government stringency index for this year only. The data were available on national scales, except for Canada, the United States, the United Kingdom and Australia, where we used subnational data (Supplementary Fig. 1).

As a general indicator of the distribution of wealth at subnational levels, we used GDP per capita, which we extracted for each studied location from a gridded dataset (Supplementary Fig. 2) for the year 2015 with 5 arcmin (~10 km) resolution[21]. We performed this extraction in ArcGIS Pro 3.0.3 using the 'Extract Values to Points' function.

Regarding the classification of reported UGS, we categorized them into different green space categories depending on their functional and structural characteristics. Although the terminology used across studies varied, we coded the study results into the following overarching categories: (1) private gardens (including yards and balconies), (2) UGS near home (including roadside green space), (3) forests and nature reserves (including watersides and all natural and semi-natural remnants of vegetation and vacant land that are not maintained in a park-like manner), (4) public gardens and urban agriculture (including community gardens and publicly accessible agricultural fields), (5) UGS unspecified (many papers do not differentiate types of UGS, including those that rely on the generic 'park' category provided by Google and Apple mobility reports), (6) public parks (maintained by municipalities for leisure and other purposes), (7) historic gardens (typically gated, with restricted entry based on fees).

Data analysis

To map the results of the included locations, we obtained geographical coordinates for each city covered by an article. We used the 'Geography data type' formatting in Excel and conducted additional searches in Google Maps when necessary. In cases where only larger administrative units were indicated in the studies, we used the respective capital cities as the locations. We used QGIS to display locations on a world map in the Equal Earth projection[70]. We used the 'point displacement' function to display overlapping points aligned in a circle around a central location.

We mostly analysed data at the location level (that is, for each city where results were reported). In the few cases where the articles reported adverse results for different types of UGS within the same city, we used the average change across all types to avoid articles with very high detail of reporting becoming too dominant in the overall analysis. For the direct comparison between UGS types we analysed available results for each UGS separately.

We coded the studies based on whether they reported overall increase, decrease or no change in UGS use. We included studies with different methodologies and detailed study questions, resulting in a mix of studies reporting general changes, and others providing more specific insights. To enable global comparability, we simplified results by summarizing them for each location and differentiating between overall reported increases and decreases in UGS use frequency or duration or a combination of both, depending on the respective study methods. For studies that reported the proportions of people who increased, decreased or did not change UGS use, the relative majority was decisive. In a subset of studies, we specifically analysed the magnitudes of change in UGS use. To be included in the analysis of change magnitudes, studies had to be based on quantitative surveys as a comparable methodology, report sample sizes and provide their results as relative changes in UGS use as percentages.

To compare COVID-19 stringency and GDP per capita between cases of decreased versus increased use of UGS, we employed logistic regressions. We adopted this approach to facilitate a binary comparison and to account for the study score from critical appraisal as a weighting variable. Although this binary approach required us to disregard the few cases of reported 'no change', it allowed us to use a more robust statistical test of the GLM-type (generalized linear model) with a binomial distribution family. We also plotted the relative changes against COVID-19 stringency and GDP, weighted by sample size, for visual interpretation.

To assess changes in UGS use across different types of green space, we grouped the numbers of studied categories in contingency tables. We conducted a statistical comparison of the distribution of contingency tables with an expected random distribution, using a X^2-test, weighting the results on the basis of the study scores with the weights package[71] in R. The distribution of these categories was displayed in mosaic plots, weighted by study score, using the vcd package[72] in R. All other data visualizations were performed using the ggplot2 package[73]. To display means and error bars, we calculated means with 95% confidence intervals using the Rmisc package[74].

During the writing process of this work, we used generative AI and AI-assisted technologies, specifically ChatGPT, to improve the language for clarity and conciseness. After using this tool, we thoroughly reviewed and edited the content and we take full responsibility for the content of the publication.

Sensitivity analyses and publication bias

To present the validity of studies from critical appraisal, we displayed their scores in the figures and included them as weights in the statistical tests. Although the majority of the 12 qualitative studies were of high quality, all except one had a sample size (number of study participants) <28 and were assigned score 1 when they were combined with quantitative studies. This is because their power to produce statistically significant results regarding the extent of UGS use is low. The qualitative

study with a sample size of 248 was assigned a score of 5 as it scored high on all criteria. This approach gave more importance to studies with high methodological strength and enough power to detect statistically significant results, thus ensuring more reliable results in the analysis without neglecting others. For a subset of studies that reported magnitudes of change based on quantitative surveys we also included sample sizes, representing numbers of surveyed individuals as weights in the analysis to account for their statistical strength.

As additional sensitivity analyses, we ran the logistic regressions with COVID-19 stringency index and GDP per capita as explanatory variables and change in UGS use on a subset of high-validity studies (score of 4 or 5). Furthermore, we ensured that the omission of the 'no change' category from the statistical analysis did not influence the results by analysing 'increase' against 'no change + decrease' in one model and 'decrease' against 'no change + increase' in another model. All variants resulted in *P* values at the same significance level, given the overall low number (6 for before–during, 7 for before–after periods) of reported 'no change' cases.

We discuss publication bias based on the distribution of studies reporting increase, decrease or no change in combination with their geographical distribution and their validity scores. We did not expect a strong publication bias between increase or decrease, as there is no obvious reason why either of them would be more likely to be reported. However, there might be a bias toward not publishing studies that show no change over time.

Deviations from the protocol

We did not use the ROSES reporting standards[75] stated in the protocol following a request from the journal editor to use PRISMA.

In the protocol we state that double screening will be applied for at least 100 references and then continue until sufficient agreement is reached. In fact, we double-screened all articles and added a third screener in cases of divergent results.

In the inclusion criteria, we previously stated that only countries with lockdowns will be included. However, we did include countries such as Sweden that did not have formal lockdowns but were still affected by COVID-19 and did apply certain social distancing measures.

We did not systematically conduct additional searches on Google and Baidu search as stated previously in the protocol as an initial screening of the first 100 hits showed strong overlaps with the results generated by Google Scholar. We also did not include studies in Portuguese, as we could not find a person with relevant language expertise and time to screen articles.

Finally, we modified the criteria to conduct a critical appraisal of qualitative studies. The original criteria reflected our unconscious bias toward quantitative studies when creating it and were not suitable for qualitative studies due to their different epistemological perspective[65].

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

Data availability

The pre-published systematic review protocol is available via Zenodo at https://doi.org/10.5281/zenodo.7244528 (ref. 28). All data extracted from published articles, together with all included references and extracted quantitative data (including a README tab), are provided as a table in Supplementary Data 1. The PRISMA checklist is provided as Supplementary Data 2. A table of excluded articles is provided as Supplementary Data 3. Additional figures, the search history, statistical results and a list of extracted quotes as a base for Fig. 5 are provided in the Supplementary Information. Published data from other sources (namely COVID-19 policy strictness and GDP per capita) are open access and available from the original studies and displayed as maps in Supplementary Figs. 1 and 2.

Code availability

All R codes used to produce analyses and figures are provided in Supplementary Code 1.

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Author contributions

F.K., S.S., L.F. and I.K. planned the project and the study protocol; F.K., P.M. and Y.C. searched for articles: F.K., S.S., P.M., L.F., K.J. and Y.C. screened the articles; F.K., P.M., J.S., Y.C. and K.J. extracted data; F.K. and S.S. analyzed the data; F.K. prepared the figures and wrote the first draft; F.K., I.K., L.F., S.S., K.J. and Y.C. wrote and revised the paper.

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Data analysis	We used code in R version 4.1.3 for data management, exploration, statistical tests and visualization. We used the following packages: weights (version 1.0.4), vcd (1.4-11), ggplot2 (3.3.5), Rmisc (1.5)

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Data collection	Data was collected from published papers by three people who checked and corrected each other.
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