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Research Paper

Do we have enough recreational spaces during pandemics? An answer based on the analysis of individual mobility patterns in Switzerland

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HIGHLIGHT
• We present a new way to assess the sufficiency rate of recreational areas harnessing travel diary data.
• Many current public open spaces in cities and small towns are already saturated by recreational demand in normal times.
• The COVID-19 pandemic has decreased the sufficiency rate for walkable areas by a factor of 1.7.
• Tranquillity is the main landscape characteristic that fosters recreational walks.

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ABSTRACT

Densification of cities threatens the provision of public open space for people living in and around cities. The increasing evidence of the many benefits of recreational walking for physical and mental health during the COVID-19 pandemic has highlighted an urgent need for fostering the availability of public open space. In this context, urban planners need information to anticipate recreational needs and propose long-term, resilient solutions that consider the growing demand driven by increasing urban population and intensified in times of crisis such as the recent pandemic. In this paper, we harness the unique large MOBIS:COVID-19 GPS travel diary data on mobility behaviour collected during a normal baseline period and during the first wave of the Covid-19 pandemic in the Canton of Zurich Switzerland. We estimate a sufficiency rate that allows to geolocate locations where the demand for public open space is higher than the available offer. In a second step, we explore if preference patterns for recreational areas have changed during the pandemic. Results indicate that the main cities and important towns in the case study area are saturated by current demand, and that the pandemic has amplified the problem. In particular, urban dwellers look for tranquil areas to recreate. Such information is crucial to guide decision-making processes for planning the cities of the future.

1. Introduction

Global pandemics, in particular the recent Covid-19 outbreak, have caused unprecedented decrease in travel (Apple, 2021; Axhausen, 2020; Google, 2021) accompanied by an increased risk of physical and mental illness (Lesser & Nienhuis, 2020; Peçanha, Goessler, Roschel, & Guallano, 2020; Zhang, Zhang, Ma, & Di, 2020). Public open spaces (pedestrian streets, green spaces, sidewalks, trails, pedestrian squares, etc.) are known to provide important health benefits to dwellers (Coutts & Hahn, 2015), providing recreational areas for physical activities, relief from stress and promoting social contacts (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Hartig, Mitchell, de Vries, & Frumkin, 2014; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Mitchell & Popham, 2008). The demand for public open space in times of stress and anxiety arising from household confinement, economic recession, and income losses has strongly increased during the Covid-19 pandemic (Venter, Barton, Gundersen, Figari, & Nowell, 2020), but these spaces are also increasingly put under pressure by the need to...
accommodate the growing urban population in densified cities (Haaland & van den Bosch, 2015).

Walking and cycling have provided a Covid-safe way for residents to get around (Nikitas, Tsigidinos, Karolemeas, Kourmpa, & Bakogiannis, 2021) and enhance well-being (Musselwhite, Avineri, & Susilo, 2020). Mobility data derived from bicycle and pedestrian counts (Doubleday, Choe, Isaksen, Miles, & Errett, 2021), mobile phone data (Chang et al., 2021; Nouvellet et al., 2021), and self-reported physical activity (Beck & Hensher, 2020; Lesser & Nienhuis, 2020) confirm that changes from the period before to the period during lock-down orders are context-specific while maintaining social distancing is thus essential to make our cities more resilient to such disruptive events.

The planning of public open spaces requires more than solely assessing their dimensions. It requires a comprehensive understanding of user’s landscape preferences and their attitudes (Kienast, Degenhardt, Weilenmann, Wager, & Buchecker, 2012; Komossa, van der Zanden, Schulp, & Verburg, 2018). The presence of people in nearby recreation areas is known to be driven by landscape properties and the accessibility of the sites. These include the structure of the landscape (Komossa, Wartmann, Kienast, & Verburg, 2020), the attractiveness of the paths leading to the recreational areas (Matsuoka & Kaplan, 2008), the scenic vista or water-related properties, to name a few. Comprehensive lists of factors influencing recreational potential in an European context can be found e.g. in Kienast et al. (2012) and Willibald, van Strien, Blanco, and Wartmann, Kienast, & Verburg (2020). The presence of people in nearby recreational space, and derive recommendations for urban planning.

During March 2020, Switzerland was among the countries with the highest number of Covid-19 cases per capita in the world, one reason why the government installed an extraordinary situation following the Epidemic Act (Salathé et al., 2020). They implemented drastic social-distancing measures from Monday the 16th of March to Sunday the 19th of April (Switzerland Federal Council, 2020). Policies during that time included increased social distance and hygiene, prohibition of social gatherings of more than five persons, and staying home whenever possible (Nivette et al., 2021). Information regarding these public health measures was widely broadcasted through multiple media channels. The extraordinary situation declared by the authorities included the closing of all shops, restaurants, bars and entertainment, and leisure facilities (only food stores and healthcare institutions were allowed to open). All public and private events were prohibited (Switzerland Federal Council, 2020). These measures influenced both mobility patterns and the use of public open space. It is important to mention that during this Swiss lockdown period, urban parks and green spaces remained open (except few exceptionally concurred parks in dense areas that were closed for a few weeks). In addition, no curfews were in place, so staying home was only a recommendation and not compulsory.

The following contribution thus investigates if available public open space for recreational walking is capable of supporting the increased demand for outdoor activities in lockdown times. We compare recreational walking behaviour during a baseline period before and during a lockdown period of the Covid-19 pandemic in 2020. Secondly, we investigate landscape properties influencing people’s walking route preferences again before and during the pandemic. Thirdly, we explore the influence of sociodemographic factors on recreational walking patterns during both periods. We harness the unique large MOBISCOVID19 GPS travel diary data on mobility behaviour collected before and during the period of special measures implemented in Switzerland (Molloy et al., 2020). Finally, we reflect on how the pandemic has both changed the needs for and influenced the use of recreational space, and derive recommendations for urban planning.

2. Methods

Study area: The Canton of Zurich is an important metropolitan area in Europe spanning 1729 km² and hosting 1'539'275 inhabitants (Federal Statistical Office, 2016) (Fig. 1). The local urbanization processes have led to a highly fragmented landscape, in which remaining green spaces have to satisfy demands for new residential areas, agriculture, industry and local recreation (Grün Stadt Zürich, 2005). The Canton is characterized by a heterogenous mix of densely built urban structures with residential, commercial, and industrial areas, urban green space ranging from forest, agriculture, and wetland to a diverse and scattered mosaic of gardens, lawns, and parks (Federal Statistical Office, 2016). As population grows and the associated demand for new infrastructure increases, there is increased pressure on the remaining green spaces. As such, the cantonal department in charge of green space management has set up important schemes for multifunctional public open space management (Jahrl & Schmid, 2017). The current pandemic has however highlighted the strong pressure on open space in the Canton of Zurich (Kleinschroth & Kowari, 2020), and highlights the importance of rethinking urban planning in this context.

Sufficiency rate of public open space: The sufficiency rate of open public spaces available for recreational walking was calculated for each one hectare cell raster combining the supply of and the demand for public open space as follows:

\[
\text{Sufficiency rate} = \left( \frac{\text{Supply}}{\text{Demand}} \right) \times 100
\]

Values under 100% indicates that there is not enough public open space for the inhabitants to enjoy walking as a recreational activity.

Demand for public open space: The demand for public open space was based on walking patterns obtained from GPS tracking data collected on user’s smartphone during the frame of the research project “Mobility Behaviour In Switzerland” (MOBIS) and its extension MOBISCOVID19 that is a collaboration between ETH Zurich, the University of Basel and the Zurich University of Applied Sciences. During the MOBIS study, participants’ mobility patterns were recorded with the GPS tracking app, Catch-my-Day, which logs their daily travel on all transport modes (Molloy et al., 2021). 3'680 persons living in Switzerland were recruited in September 2019 to participate in the mobility pricing field experiment and tracked for 8 weeks. At the start of March 2020, 1600 participants volunteered to reactivate the tracking app. Since then, weekly reports have been produced online (MOBIS Covid19 Mobility Report, 2020). The trip purpose was either selected by the participant directly on the app, or estimated using location characteristics and a random forest approach (Molloy et al., 2021).

To filter recreational walks from all the participant’s movements, we considered round trips (starting and ending at the same location) labelled as “leisure” activity and “walking” as mode of transportation. In addition, we only took into consideration those trips longer than 5 min in order to avoid the inclusion of waiting times movements, for example during a connexion when using public transport. Data from September
to November 2019 was considered as the baseline period. Data from the 15 of March (lockdown announcement) to middle May 2020 was considered as the Covid-19 period. The daily average percentage of people that took a recreational walk was calculated for both periods and amounted to 6.3% during baseline period and 9.7% during Covid-19 period, respectively. The median distances walked during each period amounted to 810 m and 1770 m during baseline and Covid-19 periods, respectively. These distances were used to create a buffer, that represents the area from which people could reach a raster cell (a service area), around each raster cell. Service areas and population data allowed then to estimate the potential number of people demanding public open spaces at each raster cell location. Based on population data (Bundesamt für Statistik BFS, 2014), we calculated the amount of people per hectare and day undertaking recreational walks (demand) by multiplying the number of people living in the buffer area by the percentage of people conducting recreational walks, which, as mentioned, increased from 6.3% to 9.7% from baseline to the Covid-19 period based on the MOBIS: COVID-19 data. In order to remove boundary effects on our analysis, we added a buffer to account for inhabitants from the neighbouring cantons that could potentially use parks and walking infrastructure in Canton of Zurich based on the median distance walked for recreation. Results for both periods can be seen in Fig. 2. Direct estimation of recreational demand from the MOBIS dataset was not possible since the participants sample size do not cover evenly the Canton of Zurich.

Supply of public open space: For the estimation of the supply of public open space, we used the SwissTLM3D dataset (Bundesamt für Landestopografie swisstopo, 2020) to identify the amount of walkable area per hectare. We focused our analysis on areas where walking was possible, removing water surfaces and dense forest areas (Fig. 3). Finally, we also removed a small number of cells where we observed extreme values caused by a high demand not linked to recreational walking, such as the airport area and shopping malls. Public open space considered include public parks, public beaches, sport surfaces, walkable paths, streets up to three meters’ width, and sidewalks of large streets. Space requirements per person were based on Grün Stadt Zürich (2005) numbers, which propose a capacity of public open space of 200 persons/ha (meaning 50 m²/person, so an area of approximately 7 by 7 m). The supply of public open space is then calculated as the number of persons that could fit the walkable surface available in each hectare cell. Finally, we considered a daily availability of the supply in order to be consequent with our demand that was also calculated on a daily basis.

Landscape properties and mobility pattern: In order to investigate changes in people’s preferences for landscape properties before and during the Covid-19 pandemic, we used various types of Generalized
Models, allowing us to describe the relation between the recreational mobility pattern and a set of georeferenced explanatory variables presented in Table 1.

As response variable, we took the sum of the walked distance surveyed with GPS and reported in the MOBIS:COVID-19 dataset per ha. As crowded locations will have more trips, we weighted the walking distances per cell using the population density at each cell. Finally, we divided the distance values by the number of days in each period. We conducted separated analyses for each period in order to check for difference between the baseline and the Covid-19 period (Fig. 4). Response variable characteristics are given in Appendix 1.

The explanatory variables were selected based on the work of Willibald et al. (2019) and Kienast et al. (2012), both investigating outdoor recreational patterns and covering the Canton of Zurich. Willibald et al. (2019) conducted a thorough literature review to select landscape variables that can explain outdoor recreation demand in Switzerland. Those variables were grouped into eight thematic groups that are consistent with the variables proposed by Kienast et al. (2012). The thematic groups include settlements, road network and accessibility, roughness and aspect, infrastructures for outdoor activities, streams and rivers, lakes, woodlands, and land use/cover. The Visibility Index (Lienhard and Binna, 2013) was added to complement mean slope and altitude on the “roughness and aspect” thematic group, because slope and altitude variability is low in the Canton of Zurich. Two additional datasets recently developed and addressing important landscape features were also included: a tranquillity index (Leeb et al., 2020) and vegetation height (Ginzler, 2018). The tranquillity index was computed based on a large list of visual and acoustic factors (Leeb et al., 2020). Most important factors included noise from cars and motorbikes, people’s presence, and urban developments, as factors influencing negatively the tranquillity. In contrast, birdsong, peace and quiet sounds, and seeing a natural landscape were the more important positive factors included in the index. Table 1 presents the 17 predictors variables considered in the study.

The initial 17 predictor-variables were reduced to 12 because of highly positively or negatively correlated variables (absolute Pearson r > 0.60). The removed predictors were lakeshore length, river shore length, share of forest, share of grass, and area of settlements. Finally, 11 out of the 12 remaining predictors were log-transformed and variables with negative values (NDVI and tranquillity) were transformed by adding the minimum value to all data points, so that only positive values remain (maps and descriptions of the final 12 variables selected are presented in Appendix 2 and 3, respectively). The dependant variable was multiplied by 100 to generate integer values, since it is a
We tested several count data models, namely the Poisson, Quasi-Poisson and Negative Binomial models. Many cells in our datasets had however zero recreational movements, which violates the assumption used in these models. We thus decided to use more adapted models, which account for excess zeros and overdispersion (Cameron & Trivedi, 2013; Lambert, 1992; Zeileis et al., 2008). In particular, we used a Hurdle (Mullahy, 1986) and a zero-inflated model (Lambert, 1992). The Hurdle model does not assume that the zeros and positive counts originate from the same data-generating process, and uses a two-step procedure with a logit model to distinguish counts of zero from counts larger than zero, and a truncated count data model for positive counts. In contrast, the zero-inflated model assumes that zeros may come from either the point mass or the count component. The regression analyses

**Table 1**

Georeferenced explanatory variables used to predict the sum of the walked distance per hectare adjusted for population. Detailed descriptions of the variables are presented in Appendix 3.

| THEMATIC GROUPS | VARIABLES | Units (all calculated per hectare cell) | Source | Spatial resolution |
|-----------------|-----------|-----------------------------------------|--------|-------------------|
| Settlements     | Area of settlement area | m² | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| Road network and accessibility | Distance to public transport | m | (Zürich, 2021) | 1 m |
| Roughness and aspect | Mean slope | o | SwissALT3D (Federal Office of Topography swisstopo, 2018) | 2 m |
| | Mean altitude | m | SwissALT3D (Federal Office of Topography swisstopo, 2018) | 2 m |
| Infrastructures for outdoor activities | Visibility index | % of area with direct view | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 100 m |
| (hiking, biking) | Density of hiking trails | m² | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| Streams and rivers | Length of stream and river shores | m | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| | Distance to streams and rivers | m | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| Lakes | Length of lakeshores | m | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| | Distance to lakes | m | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| Woodlands | NDVI | no unit | Dr. Achilleas Psomas, WSL | 10 m |
| | Share of forest | % | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| Land-use/-cover | Vegetation height (VHM) | m | Ginzler, 2018 | 1 m |
| | Share of shrub | % | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| | Share of grass | % | SwissTLM3D (Bundesamt für Landestopografie swisstopo, 2020) | 0.2–3 m |
| | Number of land-use classes | Count within a radius of 200 m | Swiss Land Use Statistics (Swiss Federal Statistical Office, GEOSTAT) | 100 m |
| Disturbance | Tranquillity index | no unit | Leeb et al., 2020 | 100 m |

Fig. 4. Walked distance per ha during baseline (left) and Covid-19 period (right) adjusted for population for the Canton of Zurich, Switzerland. Each cell is showing the daily average of the amount of meters walked during the period divided by the population density. Lighter colours mean fewer meters of recreational walks took place relative to the residential population; darker colours mean more meters were walked relative to the residential population.
Fig. 5. Walking areas sufficiency rate (%) for the Canton of Zurich during (a) baseline period, and (b) Covid-19 period (zoom-in to Zurich city and Winterthur). Red colours mean the recreational walking space is saturated so it is not enough for the residents in the service area of the pixel. Purple colours indicate that the recreational walking space is enough but close to saturation.
were run in R (using R x64 4.0.3) and we constructed independent models for each time-period.

Model performance was evaluated using Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Log Likelihood criterion (Log-Lik). In addition, predictive power was evaluated with the 10-fold cross-validation method. In the latter evaluation, data was split into 10 folds and the model fit 10 times to the data leaving out one fold at a time (i.e. training data). The model was then validated with the left-out folds (i.e. test data). The predictive power was then quantified by calculating the mean absolute error (MAE) and the root mean square error (RMSE) for both the training and test datasets.

In order to identify the important explanatory variables, we used a permutation-based approach (Wei, Lu, & Song, 2015), in which all explanatory variables were iteratively randomly shuffled and the impact on the model error was checked before and after shuffling. We used the AIC as the criterion to compare goodness of fit of the models. A variable was considered important if after shuffling its values, goodness of fit criteria decreased compared to the unpermuted model.

Mobility patterns of different sociodemographic groups: Since each participant of the MOBIS:COVID-19 dataset filled sociodemographic information, we were able to calculate the mobility patterns (daily recreational distance walked during each period) for different groups by simply filtering the dataset. We explored differences in gender, education level, household size and occupation.

3. Results

The sufficiency rate map during the baseline period shows that the demand for public open space is putting pressure on the available supply, in particular in dense urban areas (Fig. 5). We observe many areas with a low sufficiency rate (<100%) in the cities of Zurich and Winterthur, but also in smaller towns like Bülach, Uster, Wetzikon and Dietikon. In addition, these areas are surrounded by areas where sufficiency rate values are low and could easily become saturated in the future or during sunny days. In the Covid-19 period, we observe a clear increase of the pressure on walkable areas, particularly in the main urbanized areas but also in the surroundings. The pressure not only increased in magnitude but also in its extent (the number of cells with low sufficiency rate increased by a factor of 1.7 during the Covid-19 period). Interestingly, the general pattern between both periods is very similar, highlighting the importance of managing current recreational areas for additional demand.

Results of the Hurdle and zero-inflated are shown in Table 2. We observe that in both periods, the goodness of fit for both models is very similar with the zero-inflated outperforming the hurdle model slightly. The results of cross-validation show similar values for the mean absolute error (MAE) and the root mean square error (RMSE) for both models between training and test data, and model coefficients show that algebraic signs agree between the different count models, which indicates

| Table 2 |
| --- |
| Summary of fitted count regression models: regression coefficients and goodness of fit results for the Hurdle and zero-inflated models for the baseline period (left) and the Covid-19 period (right). In red: negative influence, in green: positive influence on dependant variable. |

| Explanatory Variables | Baseline period | Covid-19 period |
| --- | --- | --- |
|  | Hurdle model | Zero - inflated model | Hurdle model | Zero - inflated model |
| Dist. to public transport | 0.130610 | 0.139789 | *** | *** | -0.034460 | -0.035420 |
| Dist. to rivers | -0.005192 | -0.005407 | *** | *** | 0.009386 | 0.009841 |
| Dist. to lakes | 0.001657 | 0.005544 | *** | *** | -0.020850 | -0.020530 |
| Trail density | 0.091851 | 0.091811 | *** | *** | 0.047876 | 0.048106 |
| Share of shrubs | -0.014902 | -0.012689 | *** | *** | -0.023710 | -0.024050 |
| Altitude | -0.350751 | -0.345786 | *** | *** | 0.004980 | 0.000314 |
| Slope | -0.369584 | -0.371713 | *** | *** | 0.025722 | 0.024100 |
| No. Land - use classes | -0.197275 | -0.197879 | *** | *** | 0.019800 | 0.019768 |
| Tranquility | 1.411787 | 1.420869 | *** | *** | 1.440135 | 1.466454 |
| Vegetation height | 0.208921 | 0.207607 | *** | *** | -0.098760 | -0.099330 |
| NDVI | -0.234127 | -0.269727 | *** | *** | -0.152130 | -0.162000 |
| Visibility | -0.282819 | -0.271811 | *** | *** | -0.104010 | -0.103250 |

| Criterions: | | |
| Log-Lik | 311 231.1 | 310 947.2 | 270 036.4 | 269 965.6 |
| AIC | 622 516.2 | 621 948.5 | 540 126.8 | 539 985.1 |
| BIC | 622 781.5 | 622 213.7 | 540 392.5 | 540 250.8 |
| Cross-Validation | Training | Test | Training | Test | Training | Test | Training | Test |
| MAE | 399.31 | 399.34 | 395.31 | 395.34 | 227.92 | 227.95 | 227.71 | 227.74 |
| RMSE | 1 717.947 | 1 717.02 | 1 718.77 | 1 717.184 | 534.98 | 534.92 | 534.93 | 534.88 |
good predictive performance and no overfitting. Regarding the variable importance, we observe, on the one hand, a consistent influence of the variables trail density and tranquility (positive influence) as well as NDVI and visibility (negative influence) on walked distance throughout both periods. On the other hand, we see a change of signs between the baseline and the Covid-19 periods for several variables, including distance to public transport, distance to rivers, distance to lakes, altitude, slope, number of land use classes and the vegetation height. While distance to public transport and vegetation height exerted a positive impact on walked distance in the baseline period, they changed to a negative influence in the Covid-19 period. In contrary, altitude, slope and number of land use classes, to only name the more substantial ones, changed from a negative influence during baseline period to a positive influence on walked distance during the lockdown.

Furthermore, both the Hurdle and the zero-inflated models show similar pattern with regard to permutation-based variable importance (Fig. 6). During both periods, both models show that tranquility is the most important factor followed by the distance to public transport and visibility. During the baseline period, public transport is more important than visibility, a situation inverted during the Covid-19 period. The remaining variables are of relatively low importance, and permuting those variables only led to relatively minor changes of AIC (<1000).

The above patterns are however all based on the median distances walked during the baseline period (810 m) and during the Covid-19 period (1770 m). In the following, we provide some more insights into the mobility behaviour of different population groups (Fig. 7). Interestingly, women walked more than men, both during the baseline period and during the Covid-19 period. Furthermore, during the lockdown,
those who completed higher levels of education increased their walking to more than the double of the distance they used to walk during the baseline period. We also observed that during the baseline period, households with 2, 3 or 4 members walked more than single-person households, but this tendency changed during the Covid-19 period where we saw that single households were the ones that walked more. Finally, we observed that retired persons walked the most, and that the unemployed only slightly increased their activity.

4. Discussion

Having enough and good quality walkable space in the surroundings is known to motivate dwellers to recreate outside (Poortinga, Bird, Hallingberg, Phillips, & Williams, 2021), and is not only crucial for personal physical and mental health (Pouso et al., 2021; Soga, Evans, & Fukano, 2021), but also for fostering interactions with neighbours and the living space (Dixon & Durrheim, 2000). Global pandemics, as experienced during the COVID-19 outbreak, combined with the increasing densification of settlements can however put these spaces under pressure. The results of this study show a decrease in sufficiency rate for walkable areas by a factor of 1.7 during the COVID-19 pandemic compared to the period before. The pattern was observed in both larger cities and small towns in the Canton of Zurich, Switzerland, calling for creative urban planning strategies to secure public open spaces while densifying the neighbourhoods to reduce sprawling.

Several studies have explored the reasons behind people’s behaviour when selecting recreational areas. In general, our findings show that people have similar walking patterns before and during the pandemic. We highlight the importance of tranquillity and the distance to public transportation for recreation – two factors which have also been identified as essential for predicting recreational areas in slightly different contexts (Kienast et al., 2012; Polat & Akay, 2015; Willibald et al., 2019). It must be noticed that for the factor of distance to public transport (which can also be interpreted as the distance to main transport arteries), we observed a negative regression coefficient during the baseline period contrasting with a positive sign during the pandemic (Table 2). This indicates that during the baseline period, people were recreating further away from main transport arteries (consistent with a search for tranquillity), situation that changed during the pandemic when transportation was drastically reduced. We also observed a change in the extent of walking activities and that the change in transportation modes during the COVID-19 outbreak significantly influenced walking location choices. Particularly, areas in the surrounding of dense urbanized zones, including forests and protected areas, were visited more often, findings also reported elsewhere (Venter et al., 2020). Other studies mentioned a tendency to look for higher trees, higher vegetation coverage and more recreation in remote areas (Bereitschaft & Scheller, 2020), a behavior we did not observe in this study. Contrasting results about the amount of recreational activity during the pandemic period have been found: While some studies reported a strong increase of activity (Venter, Barton, Gundersen, Figari, & Nowell, 2021), others reported a decline in outdoor recreation (Rice et al., 2020). These differences in people’s locational choices for nearby recreation have been related to the diversity of government management strategies during the pandemic (Nikitas et al., 2021), various local contexts and outbreak progresses (Doubleday et al., 2021). Interestingly, the pandemic has motivated other groups of people to use public open spaces compared to the time before the outbreak. While both women and men augmented their walked distances maintaining the proportion between them, women are used to walk more than men; (Pollard & Wagmild, 2017)), single households and retired people, which are usually less active outdoors than other groups, absolved more kilometres
during the pandemic than before (Dumith, Hallal, Reis, & Kohl, 2011; Van Cauwenberg et al., 2015). This change in behaviour might be linked to a stronger need for social interaction of these groups, observed by other authors in the COVID-19 pandemic (Ugolini et al., 2020). Finally, our sufficiency rate approach, which was fed with a representative set of individual mobility data, not only provided interesting insights into human needs for open spaces during pandemics, but allowed to geolocate areas not providing enough public open space for the demand. Such information is not only relevant to plan for general health and well-being, but also for understanding transmission and thus indirectly some level of resilience to disease (Johnson, Hordley, Greenwell, & Evans, 2021).

This study also has some important limitations related to the availability of data used in the analysis. Real-world observations of human movements, as provided by the MOBIS:COVID19, have been shown to be highly helpful to capture people’s actual behaviour and allows developing recommendations for planners. Our analysis could however be improved by analysing in more details the temporal and spatial mobility patterns and the changes in sufficiency rate across weeks or days as well as under various weather conditions (Venter et al., 2020). It is worth to mention that the travel diary data set is assumed to be representative of the whole population, but since the data was collected using an app on mobile phone devices of voluntary people, it is clear that some groups of the society will be under-represented or even absent. It can be the case of children, old people and anybody unwilling or unable to use smartphones or concerned about sharing their location behaviour.

Furthermore, while the baseline data was collected in autumn, the data for the lockdown period was collected during spring. It would have been optimal to have data from the same periods of the year to avoid cold/warm season differences. Fortunately, the seasonality effect should only be moderate in our case study area: The temperature during the baseline months of September, October and November 2019 was in average 10.8 °C, which is very similar to the 10.7 °C measured for the months of March, April and May (Federal Office of Meteorology and Climatology MeteoSwiss, 2020). As suggested by (Hagströmer, Rizzo, & Sjostrom, 2014; McCormack, Friedenreich, Shiell, Giles-Corti, & Doyle-Baker, 2010), such relationships would however be worth investigating in more details, despite that other studies suggest that the influence could be mild (Badland, Christian, Giles-Corti, & Knuiman, 2011).

In addition, while our results show that sociodemographic differences influence walking patterns, the data used on the supply side of our analysis did not allow to investigate the relationships between various groups of people and landscape properties of green areas in more details. As highlighted by Burnett, Olsen, Nicholls, and Mitchell (2021) or Haase (2020), linking the individual mobility data with income-related information could help identify inequalities in access to public open spaces.

Finally, we considered that all open spaces could be used for recreational walking. However, many surfaces in open spaces are also used for other purposes such as connection paths or public services, which remove the space available for other recreational activities. This extra pressure on open areas was not considered in this analysis. Investigating other trip purposes would provide a more holistic understanding of the use of walkable areas, and downscaling the approach to a smaller grid size would allow to investigate the importance of various landscape elements, such as hedgerows and small gardens, that our 1 ha resolution does not allow to include.

In summary, our research shows that walking infrastructure is essential for supporting high quality of life in cities. Pandemic scenarios with lockdowns like the one provoked by Covid-19 during 2020 put extra pressure on available public open space. As expected, the problem is strongest in large cities, but smaller towns are also affected. We observed that people are looking for calm areas to walk for recreation, away from the main transportation axes. The search for tranquil areas has even increased during the lockdown period. Designing cities to absorb the increased need will thus require creative solutions to balance the increased need for tranquil public open spaces while planning for dense and green cities.

Appendix 1. Response variable based on the MOBIS:COVID-19 dataset. Walked distance per ha during baseline (left) and Covid-19 period (right) adjusted for population (Sum of walked distance divided by population density).

|                          | Baseline period | Covid-19 period |
|--------------------------|-----------------|-----------------|
| Number of values         | 136 340         | 138 757         |
| Number of null values    | 101 541 (74%)   | 110 531 (80%)   |
| Minimal value            | 0               | 0               |
| Maximal value            | 39 988          | 7 996           |
| Mean                     | 244.09          | 140.61          |
| Standard deviation       | 1 721.65        | 538.38          |
Appendix 2. Maps of the predictors used in the regression analysis.
Appendix 3. Description of the predictors used in the regression analysis

| Variables Description | Source | Spatial resolution |
|-----------------------|--------|-------------------|
| Distance to public transport | (Kanton Zurich, 2021) | 1 m |
| Mean slope | | |
| Mean altitude | | |
| Visibility index | | |
| Density of hiking trails | | |
| Distance to streets and rivers | | |
| Distance to lakes | | |
| NDVI Vegetation height | | |
| Share of shrubs | | |
| Number of land use classes | | 100 m |
| Tranquility index | | |

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