Integrating spatial accessibility estimates derived from crowdsourced, commercial, and authoritative geo-datasets: Case study of mapping accessibility to urban green space in the Tokyo-Yokohama area

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Abstract: Parks and other public green spaces (hereafter "urban green spaces") provide many benefits to urban dwellers, but some residents receive few benefits due to a lack of urban green spaces nearby their home/workplace. Understanding spatial variations in urban green space accessibility is thus important for urban planning. As a case study, here we mapped urban green space accessibility in Japan's highly urbanized Tokyo and Kanagawa Prefectures using a Gravity Model (GM). As the inputs for the GM, we used georeferenced datasets of urban green spaces obtained from various sources, including national government (Ministry of Land, Transportation, Infrastructure, and Tourism; MLIT), a commercial map provider (ESRI Japan Corporation), and a crowdsourcing initiative (OpenStreetMap). These datasets all varied in terms of their spatial and thematic coverage, as could be seen in the urban green space accessibility maps generated using each individual dataset alone. To overcome the limitations of each individual dataset, we developed an integrated urban green space accessibility map using a maximum value operator. The proposed map integration approach is simple and can be applied for mapping spatial accessibility to other goods and services using heterogeneous geographic datasets.

Keywords: OpenStreetMap, Volunteered Geographic Information, urban parks, urban green space

1. Introduction

Urban green spaces, such as public parks and green open spaces, offer numerous recreational, social, and health benefits (so-called ecosystem services) to urban residents (Chang et al., 2017; Graça et al., 2018). A growing body of scientific literature associates the frequent use of these green spaces with a higher quality of urban life, including improved physical and mental health, increased socialization, and higher life-satisfaction (Rigolon, 2016; Zhang et al., 2015). To fully realize these benefits, however, three factors are primarily important: the proximity, spatial extent, and quality of the urban green spaces that are available (Rigolon, 2016). Of these, spatial proximity is a critical factor affecting the use of urban green spaces (Cohen et al., 2007). The distribution of urban green space, however, often varies across space (Maroko et al., 2009), meaning that some residents have greater access to these benefits than others. This phenomenon of unequal access to goods and services is not limited to urban green space, and has been observed for various goods/services including health care (Fransen et al., 2015; Schuurman et al., 2010), supermarkets (Larsen and Gilliland, 2008), financial services (Johnson et al., 2019; Khan and Rabbani, 2015), and public transportation (Jang et al., 2017). Spatial accessibility to a particular good/service – i.e. the number of service providers at a given location and the spatial connectivity between the location and the service providers (Khan and Bhardwaj, 1994) – is commonly calculated using a Gravity Model (GM) (Fransen et al., 2015; Johnson et al., 2019; Schuurman et al., 2010), for which the basic form can be seen in Equation 1 (see Section 2).

In this study, we investigated spatial variations in accessibility to urban green space in the Tokyo and Kanagawa Prefectures of Japan, where the densely-populated cities of Tokyo and Yokohama are located. As the input to the GM, we considered the area of urban green space (m^2) accessible at each spatial unit of analysis (500m x 500m grid cell) rather than the number of service providers. One of our objectives was to identify areas where urban green space accessibility was currently lacking. For this, we utilized three geo-datasets containing the locations of urban green spaces: crowdsourced OpenStreetMap data, an "urban parks" dataset provided by the national government (Ministry of Land, Transportation, Infrastructure, and Tourism; MLIT), and a map of publically available "nature-greenery" areas provided by a commercial mapping company (ESRI Japan Corporation). The rationale for including all three of these datasets for the accessibility calculations was that some types of urban green spaces might have been omitted in each individual dataset. The remaining objectives of our study were to compare the measurements of accessibility derived from the crowdsourced, commercial, and government geo-datasets, and attempt to combine these three heterogeneous sources of geo-data so-as to better understand urban green space accessibility.

2. Methods and Data

The OpenStreetMap and MLIT datasets were freely accessible online, and downloaded from https://download.geofabrik.de/asia/japan.html and http://nlftp.mlit.go.jp/ksj-e/gml/datalist/KsjTmplt-P13.html, respectively. The ESRI dataset ("ArcGIS data collection detailed map 2015") was purchased through ESRI Japan Corporation, and includes data compiled from various commercial sources, including Zenrin Co. Ltd., a large producer of residential maps and software used in automobile navigation systems. The definition of urban green space varied for each dataset. In the OSM dataset, urban green spaces were considered as any features having a “park” tag, which includes areas of open space for recreation, typically having a semi-natural state (e.g. including grassy areas, trees, and bushes) (https://wiki.openstreetmap.org/wiki/Tag:leisure%3Dpark). These spaces are open to the public, but may be closed during some hours. Urban green spaces in the MLIT dataset include urban parks built by the government based on the national Urban Park Act (http://nlftp.mlit.go.jp/ksj-e/gml/datalist/KsjTmplt-P13.html). Urban green spaces in the ESRI dataset include parks, grasslands, wetlands, and shrines larger than 15m x 15m in size. Some of these urban green spaces (e.g. zoos, botanical gardens, or temple grounds) require a fee to enter.

Based on the data descriptions, the OSM dataset has the broadest definition of urban green space. Its degree of completeness, however varies by location because it is a crowdsourced dataset. The ESRI dataset also has a quite broad definition of urban green space, but excludes small green spaces that are common in dense urban areas. The MLIT dataset has the narrowest definition of urban green space, but includes even very small green spaces (the smallest park included in our study area was 27m^2). The file formats of the datasets also differed, as the OSM and ESRI datasets contained the polygon boundaries of the green spaces, while the MLIT dataset contained the point centroids of the green spaces (with the area information stored in the attribute table). These three datasets are thus quite heterogeneous in terms of their urban green space definitions, file formats, and degrees of geographic completeness. The locations of the urban green spaces in each dataset are shown in Figure 1.

To give the reader a general idea of the types of urban green spaces found in the study area, the number and average size of each type of urban green space in the MLIT dataset are shown in Table 1 (the OSM and ESRI datasets did not specify the type of urban green space of each polygon), and Figure 2 shows photos of some typical urban green spaces.

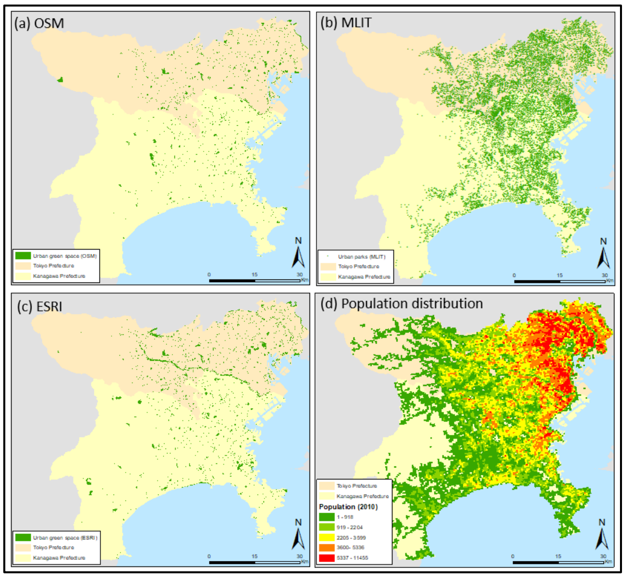

Figure 1. Urban green spaces extracted from the OSM (a), MLIT (b), and ESRI (c) datasets. 500m x 500m gridded population map (d).

Type of urban green space	Number of urban green spaces	Average size (ha)	Total area (ha)
Not specified	5,714	0.73	4171
City block park	5,114	0.17	887
Urban green space	677	1.27	858
Neighbourhood park	267	1.88	502
Scenic/zoological /botanic/historic	76	8.00	608
General park	75	12.66	949
Green path	61	0.89	54
District park	47	6.19	291
Sports park	42	7.75	325
Park square	16	0.58	9
Wide area park	8	57.24	458
Urban forest	4	0.24	1
Buffer green belt	2	1.34	3
National park	1	162.50	163

Table 1. Number of each type of urban green space in the MLIT dataset, their average area (ha), and total area coverage (ha).

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Figure 2. Photos of some typical urban green spaces in Tokyo and Kanagawa Prefectures.

"Spatial accessibility" (SA) to urban green space was defined in this study as the area of green space readily accessible (within 2 km) at a given location, inversely weighted by the distance to the green space(s). This represents the most basic form of the Gravity Model (GM), and is given by:

$$SA_i = \sum_j \frac{P_j}{d_{ij}} \quad (1)$$

Where SA_i is the spatial accessibility to parks at location i, P_j is the area (m^2) of the park at location j, and d_{ij} is the Euclidean distance (m) from point i to j. The output of the GM is a unitless index, with higher SA_i values indicating higher spatial accessibility to urban green space. Typically, d_{ij} is measured from the centroid of a census unit or grid cell to the features of interest (e.g. all parks within 2 km). In this study, d_{ij} was measured from the centroids of 500 meter x 500 meter grid cells because census population counts were available at this spatial resolution (downloaded from http://nlftp.mlit.go.jp/ksj-e/gml/datalist/KsjTmplt-mesh500.html).

3. Results

3.1 Urban green space accessibility maps produced using each individual geo-dataset

Applying the Gravity Model (Equation 1) to the OSM, MLIT, and ESRI datasets resulted in three separate maps of urban green space accessibility, as shown in Figure 3 (a)-(c). All three maps have a 500m x 500m spatial resolution, matching that of the census population data. The average SA_i value produced using the OSM, MLIT, and ESRI datasets was 1309, 733, and 1461, respectively. This indicates that the ESRI dataset produced the highest estimates of urban green space accessibility, in general, probably due to its broad definition of urban green space and higher degree of geographic completeness than the OSM dataset. The MLIT dataset produced the lowest estimates of green space accessibility, likely due to its narrower focus (i.e. only including parks on publically-owned lands).

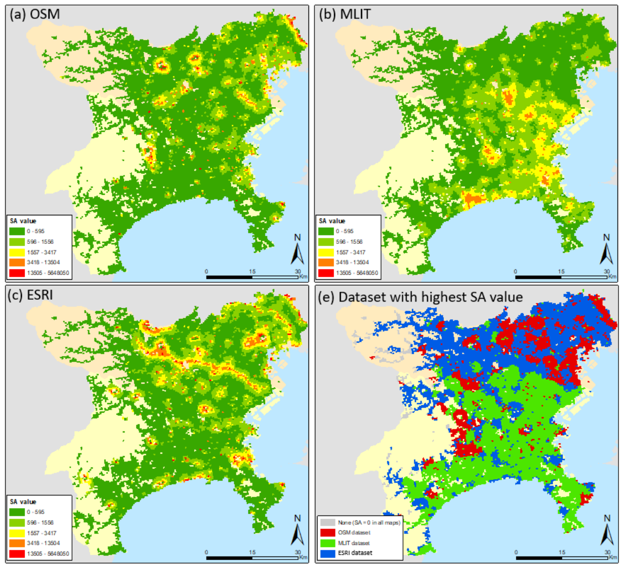

Figure 3. Urban green space accessibility (SA_i) estimates derived from the OSM (a), MLIT (b), and ESRI (c) datasets. Map showing which dataset produced the highest urban green space accessibility estimate in each 500m x 500m grid cell (d). Higher SA_i values indicate greater accessibility to urban green space.

3.2 Integrated urban green space accessibility map

To understand the differences in the spatial patterns of the three individual urban green space accessibility maps, we overlayed the maps and used a maximum value operator to identify which map produced the highest SA_i value at each 500m x 500m location (Figure 3 (d)). As shown in this Figure, the MLIT dataset generally resulted in the highest accessibility estimates in Kanagawa Prefecture, while the ESRI and OSM datasets produced the highest estimates in Tokyo Prefecture. The higher accessibility areas given by ESRI, stretching from Tokyo bay to northwest of Tokyo is a contribution of green spaces along Tama river, and higher accessibility area in the central Tokyo is due to large green spaces offered by imperial palace, both of which are not categorized as urban parks, thus unable to be captured by MLIT. The higher accessibility estimates given by OSM in Eastern part of Tokyo Prefecture suggests the presence of more OSM volunteer mappers there, which is likely due to the high population density in this area.

To overcome the limitations of each individual geo-dataset for mapping urban green space accessibility (e.g. narrow definition of urban green space or incomplete geographic coverage), finally we developed a simple map integration procedure. This procedure consisted of overlaying the three individual maps and calculating the maximum SA_i value at each grid cell location using a maximum value operator (similarly to the process used to produce the map in Figure 3 (d)). The resultant integrated (i.e. maximum SA_i) urban green space accessibility map is shown in Figure 4. In this integrated map, it is clear that the areas of high spatial accessibility in each individual map were well preserved. Specifically, the areas with high SA_i values in the northern and western parts of the OSM map, the eastern part of the MLIT map, and the linear feature in the northern part of the ESRI map (Tama River bank) are all well preserved in the integrated map.

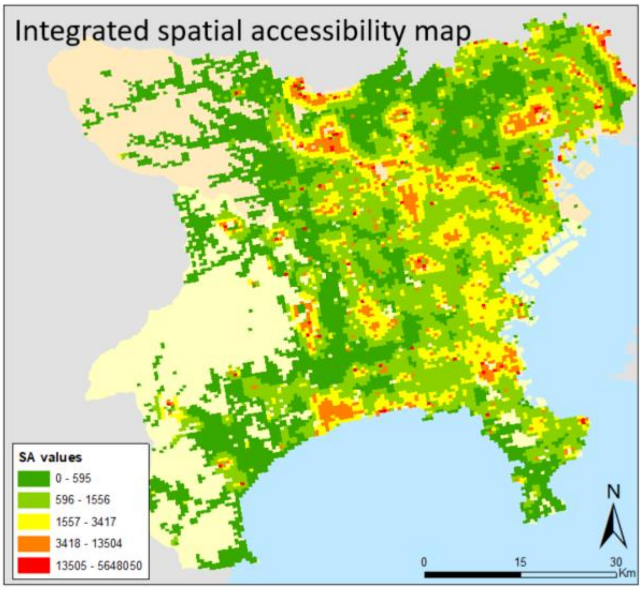

Figure 4. Integrated urban green space accessibility map derived by applying a maximum value operator to the OSM-, MLIT-, and ESRI-derived accessibility maps.

This integrated map suggests that there is currently some inequity in urban green space accessibility in Tokyo and Kanagawa Prefectures. However, we have not yet taken into account spatial variations in demand for urban green space (due to, e.g. spatial variations in population density). Further research is also planned to determine how spatial accessibility affects different residents' (e.g. families with children, single adults, or elderly residents) usage of urban green spaces in the study area. For this, we plan to combine the integrated urban green space accessibility map generated in this study with demographic data, and to conduct a survey of how (and to what degree) residents in different parts of the study area use urban green spaces.

4. Conclusions

In this study, we found that integrating spatial accessibility maps created from multiple datasets (including crowdsourced, commercial, and authoritative geo-datasets) helped to overcome the limitations that arose when creating a map from a single dataset. We used a maximum value operator to combine the three different spatial accessibility maps produced in this study (i.e. the OpenStreetMap, MLIT, and ESRI SA_i maps). However, future works could consider other (more sophisticated) approaches for this map combination.

Our integrated spatial accessibility map provides evidence that urban green space is unequally distributed in Tokyo and Kanagawa Prefectures. In the future, the populations of both prefectures are expected to decrease, so there is a possibility for the government to convert abandoned residential properties to urban green spaces to improve the quality of life of residents. However, spatial accessibility is only one component of urban green space usage, and other social, economic, and ecological factors are also necessary to consider. To follow up this study, we plan to investigate these additional factors affecting urban green space utilization.

5. References

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