樹冠被覆率と人流データによるウェルビーイングのための都市構造評価手法

A method for evaluating urban structure for well-being using tree canopy coverage and pedestrian flow data

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Abstract: We developed a method to understand the urban structure for well-being by combining tree canopy coverage and pedestrian flow data. Greater exposure to green spaces ensures greater benefits for residents of an area. By determining the degree to which the citizens of a city are close to green spaces, the degree of exposure to green spaces in that city can be quantified. We calculated the probability of encountering green spaces from pedestrian flow data and used this probability as the Green Accessibility Index (GAI). The GAI is the degree of exposure to green spaces; because the pedestrian flow data used are all-day data, we can convert this information to a 24-hour period to attain a time unit. This is called the Cumulative Green Spaces Exposure Time (CGSET). By converting the amount of exposure to green spaces into hours, we can respond to findings from measuring the effects per hour seen in public health research. By using these values to evaluate urban structure, we can consider the strategic placement of green spaces, and in the competition for their use in urban areas with limited space, we can theoretically organize the trade-off between the multifunctional benefits of green spaces and the functions that could be realized if the spaces were utilized differently.

1. Introduction

The impact of urban green spaces on people's health has become well known in recent years[1)]. From a public health perspective, it is necessary to keep social and environmental factors in mind when approaching health maintenance as well as the medical aspects[2)]. In response to these recommendations, Kaiser Permanente, a US major healthcare insurer, began to divert 2 billion US dollars a year to invest in promoting health and developing public spaces (urban parks, pedestrian and bike paths, etc.) from a total research sum previously earmarked for healthcare[3)]. Given this greater focus on the benefits of urban green spaces, the World Health Organisation Regional Office for Europe (WHO/Europe) conducted a systematic review of relevant papers and published a report in 2016[1)], which they then used to advocate the effectiveness of urban green spaces in urban policy in 2017[4)]. The 2016 report confirms that urban green spaces can significantly boost overall health, notably by reducing the morbidity and mortality of heart disease and reducing the risk of obesity and type 2 diabetes. The report also shows that urban green spaces can play a part in developing countermeasures for non-communicable diseases (NCDs), which comprise 71 percent of global mortality[5)]. Moreover, improving the conditions of expectant mothers before birth, effects on childhood growth and involvement in the development of the immune system are also highly associated with the issue of declining birthrate faced in Japan. As for the psychological effects of urban green spaces, their benefits for relieving and improving stress, enhancing self-esteem and motivating people to take action are also clear. The report concluded that they help promote social interaction and foster a sense of community as a result. This is also related to issues of dementia and the social isolation of senior citizens[1)].

The mental and physical benefits from these plants, mainly trees (hereinafter referred to as 'greenery'), urban parks, green spaces and pedestrian paths (hereinafter referred to as 'green spaces') are now interacting with one another and considered particularly crucial for improving the health and wellbeing of city dwellers, which is another group cited as a global target in the Kunming-Montreal Framework for Biodiversity, presented in 2022. In that framework, Target 12 – the need to significantly increase the area and quality of greenery and water parks, connectivity and access to such spaces in urban and high-density population areas by 2030 to improve human health and wellbeing – is stated[6)]

To effectively incorporate greenery into urban areas, it is important to determine the status quo of green spaces. One common approach has been to use a vegetation index based on satellite remote sensing called Normalized Difference Vegetation Index (NDVI)[7)] and efforts to estimate the green coverage rate in urban areas have also been attempted in Japan[8)]. Furthermore, the USDA Forest Service developed i-Tree, a system for quantitatively assessing the value of trees, which the City of New York in the USA has used to publish a map and visualise the environmental value of individual street trees[9)], while also examining scope to convert the monetary value of trees in Japan[10)]. In recent years, the Google Earth Engine has been leveraged to calculate the green coverage rate[11)], as well as developing its scoring method within walking distance based on the calculation result[12)]. Accordingly, several attempts to determine the status quo of green spaces are underway with some positive results. However, when it comes to the interrelationships between human health, wellbeing and green spaces, progress has been limited to determining the amount and distribution of greenery and we have yet to understand the actual situation, including the connections between greenery and human life.

This report aims to evaluate the urban structure supporting people's health and wellbeing by developing a method to understand the urban structure for wellbeing based on the data combination of tree canopy coverage and pedestrian flow and quantifying the degree of exposure to green spaces by the citizens, creating a distribution map.

2. Methods for building an evaluation approach

(1) Definition of terms

1) Green Accessibility Index (GAI)

Many of the studies covered in the aforementioned WHO report include contents examining the effects of greenery on humans by

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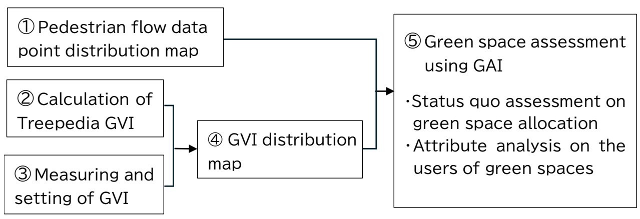

Figure 1 Structure of Green Accessibility Index (GAI)

comparing the quantity, quality and accessibility of green spaces within the daily living area of examinees and each shows that the greater the exposure to green space, the better the end effect. We therefore concluded that calculating the degree of proximity for citizens would allow us to quantify the susceptibility of exposure to greenery in that city. The novel feature in this report is an attempt to index the degree of proximity to greenery using tree canopy coverage and pedestrian flow data, which is defined as the Komorebi Index (Green Accessibility Index: hereinafter referred to as 'GAI'). This index indicates benchmarks the accessibility of greenery in urban areas and since the technology introduced in this report uses a combination of the amount of greenery and human activities, we use the term 'Komorebi', denoting exposure to the sunlight filtering through leaves. Given its iconic status to represent the relationship between greenery and humans, we decided to call it 'Komorebi Index' (Green Accessibility Index). (Figure 1)

2) Cumulative Green Space Exposure Time (CGSET)

When looking at how exposure to greenery affects mental and physical health, we need to consider the effective length of exposure. Bum-Jin Park et al. tested the physiological effects of forest bathing by setting up a 20-minute walk or observation in a natural environment [13]. In addition, Mathew P. White et al. reported that contact with nature for at least 120 minutes a week increased health and wellbeing, based on self-reported information by examinees[14]. H. K. Yuen et al. assessed the degree of stress reduction in urban parks by comparing time spent there and overall exposure in green spaces and spending at least 20 minutes a day in natural surroundings was seen to significantly ease stress[15].

The GAI is the degree of exposure to greenery. Since all-day pedestrian flow data is used, we can convert this information to a 24-hour period to attain a time unit. This is known as green space exposure time and the collective term for multiple exposure times is known as cumulative green space exposure time (hereinafter referred to as 'CGSET')[17]. Converting exposure to green spaces into hours allows us to respond to the public health research findings that measure the effects per hour.

(2) Data used

1) Tree canopy coverage

Tree canopy coverage is calculated by leveraging Treepedia[18] technology developed by the Massachusetts Institute of Technology with support from the World Economic Forum, where the data is released as open source. Treepedia measures greenery using Google Street View (hereinafter referred to as 'GSV') data and expresses it as a percentage called the Green View Index (hereinafter referred to as 'GVI'). The GVI calculates the percentage of greenery in six directions from GSV panoramic images: front, rear, left, right, sky, and ground. The total possible greenery across all six directions equals 100 percent, meaning that if one entire direction is completely covered with greenery, it contributes 16.7 percent to the total[19]. Using GSV is ideal for quantifying greenery exposure from a human perspective in street environments. It also provides a consistent method for collecting data across different regions, enabling comparative analysis between cities. The Treepedia website already features GVI distribution maps along with median values and population density data for 34 cities worldwide.[18]

2) Tree canopy coverage in green spaces

Since Treepedia is developed as a tool to help greening review on the streets and other sites in the neighbourhoods focusing on the street trees and using GSV to calculate GVI, we use GSV data mainly on the streets. Accordingly, GVI data cannot be calculated for green spaces lacking GSV data that are not streets. However, as green spaces play a key role in terms of giving citizens exposure to greenery in their daily lives, we added such plots as polygon data using a GIS software package called QGIS[20] in this report.

When calculating the GAI in green spaces with additional polygon data, we decided to count the point-type pedestrian flow data within the polygon.

3) Pedestrian flow data

As big data has penetrated in recent years, the Ministry of Land, Infrastructure, Transport and Tourism has published guidance on how to use pedestrian data to solve regional problems[21]. The data dealt with their cover all the pedestrian data obtained from various devices. In this report, we only use pedestrian data obtained from mobile terminals such as smartphones. There are two main types of pedestrian flow data using mobile terminals: 1. Those provided by telecommunications carriers, 2. Those provided by non-telecommunication carriers. In this report, we use point-type pedestrian data from the latter group, since it was easy to obtain sufficient data samples without any restrictions imposed on specific telecommunications carrier users.

Point-type pedestrian flow data is location big data that is concealed and statistically processed from GPS and other location data acquired from smartphone apps, providing information such as identification data, time of data acquisition, latitude and longitude of the measurement point and estimated place of residence. This allows the amount of people in any given location, such as a road, building or urban park, to be determined in minutes, alongside the latitude and longitude.

A tool called Profile Passport by Blogwatcher Inc. is used in this report, which provides 24 hour point-type pedestrian flow data for each specified date.

(3) Examination object

Two areas of Kishiwada City in Osaka prefecture were covered in the study (Figure 2). Zone A is a downtown area representing a 4.5 km² area centred on Kishiwada Castle, which is comprised of category 1 and 2 medium-to-high-rise exclusive residential districts, category 1 and 2 residential districts, neighborhood commercial districts, commercial district, quasi-industrial districts, industrial districts and exclusive industrial districts. Zone B represents a 3.0 km² area along the Haruki River in the suburbs, which is mostly either category 1 and 2 low-rise exclusive residential districts, category 1 and 2 medium-to-high-rise exclusive residential districts. Quasi-residential districts are partially included along the major roads. We performed GVI calculations at 5,333 sites in Zone A and 5,060 sites in Zone B (Figure 3) Point-type pedestrian flow data were analysed for a total of 16 days per year, i.e. two weekdays and two holidays during each of the four seasons (Table 1, Figure 4).

3. Urban Structure Assessment and Discussion

(1) How to operate the urban structure assessment

Define the zone of the city to be studied, then divide the number of points of the point-type pedestrian flow data (hereinafter referred to

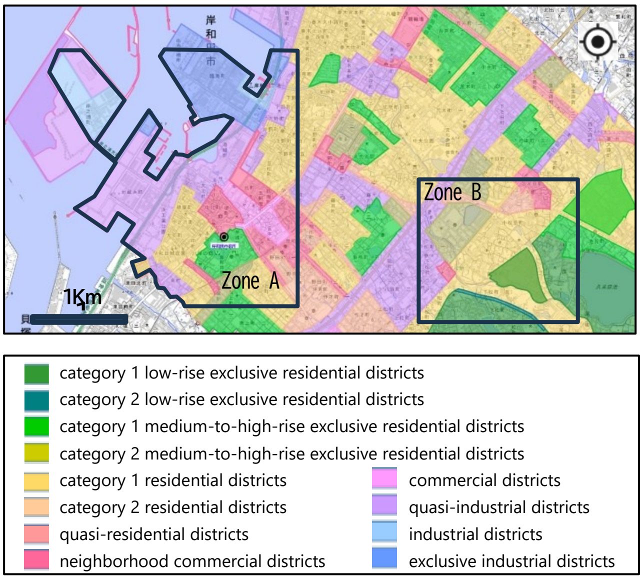

Figure 2　Zones for Examination Object

Figure 3　GVI Calculations: GSV measuring points (brown) and green spaces (green polygon)

Table 1 Analysis Dates for Point-type Pedestrian Flow

Season	Month & Year	Weekdays		Holidays	
Autumn	Oct. 2021	Thu. 7	Thu.14	Sun. 10	Sun. 24
Winter	Jan. 2022	Wed.19	Thu. 20	Sat. 15	Sat. 22
Spring	Apr. 2022	Tue. 12	Wed. 20	Sun. 10	Sun. 17
Summer	Jul. 2022	Thu. 7	Wed. 20	Sat. 2	Sun. 24

Table 2　GAI in Target Zones

Zone A	The number of pedestrian flow points-a	The number of pedestrian flow points-b	GAI30 b/a in the entire area	CGSET (min./day) 24hr × 60min × GAI
Entire area	1,491,832	39,953	0.026781166	38.6
Streets	190,804	1,524	0.001021563	1.5
Green spaces	38,429	38,429	0.025759603	37.1
Other sites	1,262,599	—	—	—

Zone B	The number of pedestrian flow points-a	The number of pedestrian flow points-b	GAI30 b/a in the entire area	CGSET (min./day) 24hr × 60min × GAI
Entire area	1,090,930	10,784	0.009885144	14.2
Streets	275,038	3,000	0.002749947	4.0
Green spaces	7784	7,784	0.007135197	10.3
Other sites	808,108	—	—	—

as ‘pedestrian point’) within the range of a five meter radius around that zone in a certain GSV measurement site by the total number of pedestrian points, which determines the percentage of citizens in the

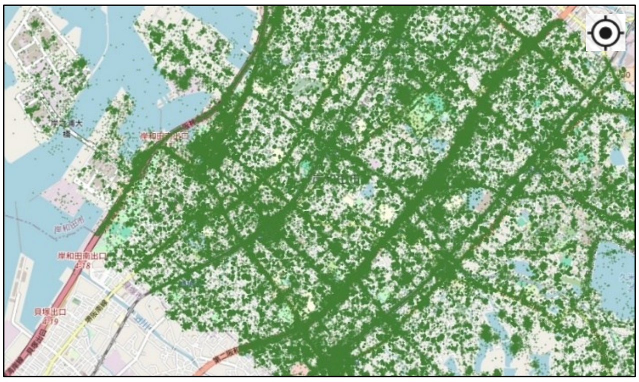

Figure 4 Plot of Point-type Pedestrian Flow Data (green dots)

study zone who are at that GSV measurement site. This then helps indicate the utilisation rate of specific locations in the zone, e.g. in urban parks and on certain streets. We can determine usage data in zones where the benefits of greenery are expected by examining the GAI, since this is computed by extracting and calculating the GSV measurement points obtained from GVI which anticipates the benefits from greenery within the relevant zone. In other words, it involves quantifying the degree of proximity and the ease with which citizens in urban areas can enjoy exposure to greenery. The GAI viewer screen, which is currently under development, allows the GVI and the number of pedestrian flow points to be shown variably, whereby GAI can be shown in four scales and in any combination (Figure 6). It is configured at four levels, i.e. high GVI with high pedestrian flow, high GVI with low pedestrian flow, low GVI with high pedestrian flow and low GVI with low pedestrian flow so that audience can intuitively understand the importance of greenery at the site.

Regarding all GVI measured in 34 cities worldwide, the maximum value is set for 60 percent or so[18]. Since the downward direction (ground) is often considered to be paved in urban areas, a GVI of 60 percent means that an average of 12 percent of the remaining five directions are occupied by greenery and if one direction occupies the maximum value, approximately 80 percent of the area would be greenery. In a study examining the effects of greenery exposure, an analysis breaking such effects into five levels from 0 to maximum showed that the effect was observed in more than half the maximum values[22) 23)]. Accordingly, in this report, the GVI value where a green effect can be expected is set at a GVI of 30 percent or more, meaning half the maximum value of 60 percent, namely six percent in this case. In other words, each of the remaining five directions, excluding downward (ground), would be occupied by greenery. If one direction were to occupy the maximum value, approximately 40 percent would be occupied by greenery. Incidentally, when the GVI is calculated with 30 percent or more, the GAI shall be indicated as GAI 30[24)].

As mentioned earlier, the GVI in green spaces without sufficient GSV data was tentatively set at 30 percent. A green space with the GVI of 30 percent can be assumed to obtain a GVI of about 10 percent in the downward direction (ground) and about five percent in each of the four lateral directions (front, rear, left and right) with grass and other ground coverage, while open space lies in the upward direction (sky). Facilities without sufficient greenery in the lateral directions which are even in green spaces, such as sports facilities, were treated as the GVI of 30 percent or less.

(2) Target zones for the urban structure assessment

Table 2 shows ’the number of each pedestrian flow points’, ‘the number of pedestrian flow points with a GVI of 30 percent and above’,

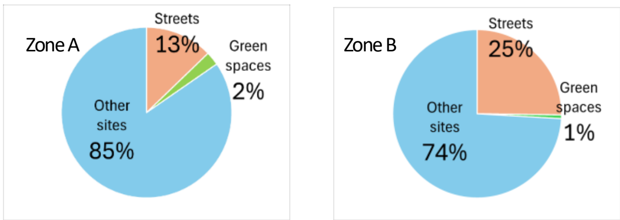

Figure 5 Pedestrian Flow Trends in target zones

'the GAI 30' calculated based on these figures and 'the CGSET' in both Zones A and B.

In Zone A located in downtown area, using other sites belonging to the private sector, etc. comprises 85 percent, which is a larger proportion than using streets (13 percent) and green spaces (2 percent) that are managed by public administration (Figure 5). We infer that people spend more time in offices, factories, commercial premises and residences. The figure of 74 percent refers to people living in the city according to the point-type pedestrian flow data within Zone A. There are four large urban parks in Zone A, all of which provide 6-8 minutes of exposure when we calculate the CGSET based on the GAI. We determined that all urban parks in the zone provide CGSET of 37 minutes. However, we found that 50.5 percent of the users of Chikiri Park, where Kishiwada Castle is located, Hama Industrial Park, which is adjacent to the coastal industrial area and Hannan District 1 Harbour Green Space, are visitors from outside the city. The other Kishiwada Old Harbour Green Space is adjacent to commercial facilities and high-rise condominium buildings and approximately 90 percent of the users are Kishiwada City residents (Figure 6).

In Zone B, the district surrounding Haruki River, much of which includes suburban residential areas, 25 percent of the area where people get exposed to greenery is on the streets (Figure 5). The percentage of the city residents in this zone, based on the point-type pedestrian flow data, is 79 percent, which is higher than that in Zone A. There are several urban parks, including community parks, within which 86 percent of users are Kishiwada City residents. Although we can confirm that some areas have grass and trees planted, which explains a

Figure 6 Distribution of the GAI 30 in Zone A

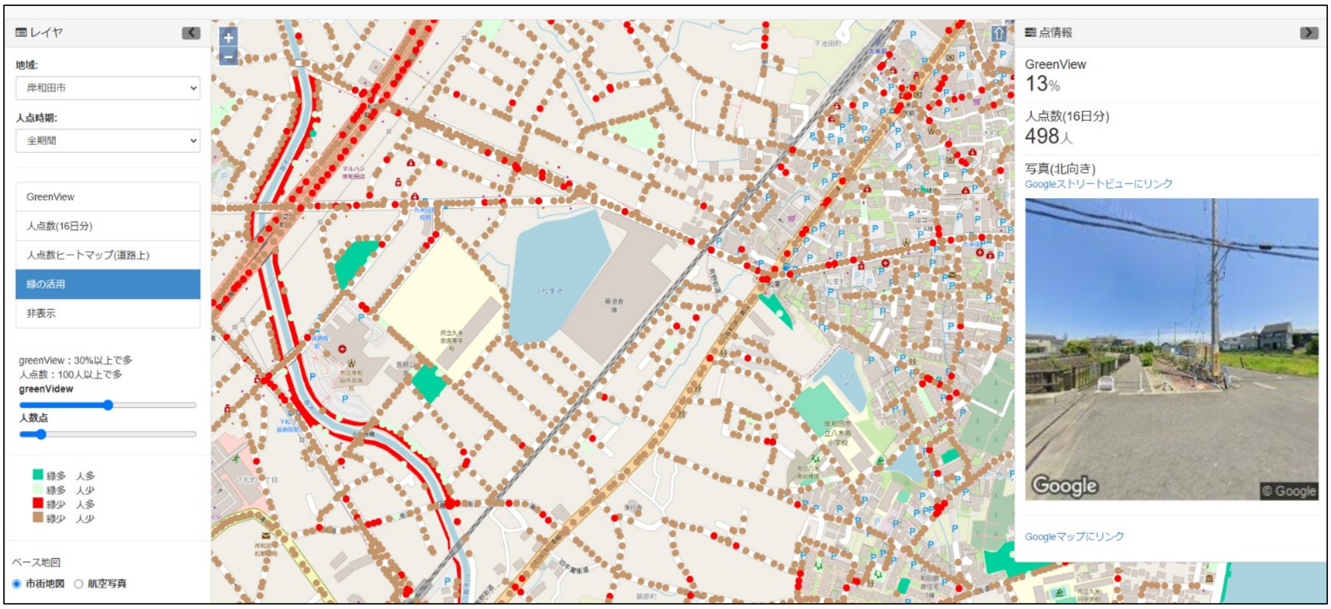

Figure 7 Distribution of the GAI 30 in Zone B

GVI of over 30 percent along the Haruki River pedestrian path, most of the path has a GVI of clearly under 20 percent (Figure 7).

(3) Considerations from the Urban Structure Assessment

Zone A includes pedestrian points of 85 percent in other sites, besides streets and green spaces. Here, we consider that we can examine how green spaces should be leveraged in a more concrete manner through public and private collaboration and planting design, etc. if we add information on greenery in private land by subdividing such land into other sites according to districts of use.use. Accordingly, we will be able to clarify the roles of each group, i.e. who takes primary responsibilities for the management of greenery and who receives benefits from such sites, which helps advance green promotion project. For example, the concrete impact of a promotional tree-planting initiative within the industrial sites and surrounding commercial premises was amplified due to indirect administrative measures, underlining how information like this plays an even more important role. Moreover, the higher percentage of residents using green spaces adjacent to commercial premises and condominiums in the city shows that we can infer the use of green space as part of their shopping opportunities as an example of their lifestyle pattern.

Recently, we often see redevelopment projects combining large-scale commercial facilities and green spaces. This suggests the potential for greenery which benefits commercial facilities, their employees, customers and the surrounding environment to also impact on consumer behaviour. It also implies that improving the GVI of these districts, i.e. promoting greening, could efficiently improve the GAI.

When such locations in Zone A are extracted from the data, those with high pedestrian flow and low GVI are shown in red (Figure 6). As you can see, a commercial complex borders the green space located in the top left of the diagram. We can confirm that the red dots connect this commercial complex with the railway station (Kishiwada Station) in the lower right in the form of a strip. The photograph of one selected GVI location (on the right of Figure 6) shows a vacant site bordering an arcade. This highlights where improvements should be made to realise a town encouraging people who want to walk in their daily lives and where living there alone can boost their health. In zone B, we should consider what type of environment is more important for a group of people there who are deeply involved in child-raising and social relationships in the community and how best to allocate such an environment for them.

We consider that the key factor of the environment is whether people can build comfortable life within walking distance from that perspective.

The CGSET in the street within Zone B is four minutes, which is more than twice as long as in Zone A. However, looking at the use of green spaces, people only spend ten minutes, which is less than a third of the time compared to Zone A. Extracting areas with low GVI and high pedestrian flow to examine means of improving CGSET based on pedestrian flow data, the result is shown in Figure 7.

For example, more than 90 percent of users walking along the pedestrian riverside path are Kishiwada City residents based on the data, which is why we consider users of such area as neighbourhood residents. There are also over 12,000 pedestrian flow points overall. That means if the pedestrian path were redeveloped to make a GVI of 30 percent and over, the CGSET would be improved by 16 minutes according to our estimate. If such redevelopment plan succeeded, further beautifying the site and the percentage of the users reached 120 percent; the CGSET would be over 20 minutes. Such improvement projects simply embody the idea of developing residential areas where people can remain healthy merely by living there.

4. Conclusion

Firstly, exploiting the technology introduced in this report paved the way for us to visualise the usage status of urban greenery based on the distribution data of pedestrian flow points and the characteristics of the target zones. Using such technology helps us understand the time spent by people in public spaces (green spaces such as streets, public facilities, parks, etc.) and private spaces (housing, industrial facilities, commercial facilities, etc.) respectively. Spaces developed by public administrations are key when it comes to equality and equity, since they allow measures to improve health and wellbeing to be directly implemented. The pedestrian flow point ratio indicating opportunities to access street and green spaces was around 20 percent. Based on this result, if public facilities like government offices, libraries and schools were included, the pedestrian flow point ratio would be increased. Accordingly, we believe that focusing on greening projects in these areas can boost the influence on greenery in urban cities. Conversely, regarding spaces developed mainly by the private sector, when assessing cooperative efforts between public and private sectors, it is important that the government can regulate and maneuver business operators in line with users' characteristics and trends in terms of visits to greenery. The results thus provide useful basic information when it comes to selecting wellbeing measures in the target zones.

As GVI varies with tree growth and its maintenance status, running a simulation using GVI as a variable number can be useful to identify sites where the GAI can be improved in a planned and effective manner. As we quantify greenery by breaking it down into several stages using GVI, which is human perception, we can assume future prospects for tree growth as well as determining what maintenance work is required and assessing the current status of greenery and whether it is sufficient or deficient. Mapping of the GVI overlaid with point-type pedestrian flow data and the derived GAI has enabled the effective development and cultivation of greenery that contributes to health and wellbeing, as well as selecting potential sites for such development.

Moreover, when assessing urban structures contributing to health and wellbeing – an area where the technology introduced in this report also plays a key role – we found that exploiting the CGSET using time to be an effective assessment method, either in the entire area of any given target zone or part of the area comprising such zones. This means the effects of measures can be assessed in a unified manner, despite being implemented using different methods. Joint projects with private business operators such as railway companies, commercial developers and shopping streets should be implemented as part of measures improving commercial areas in Zone A, while public administration also requires indirect approaches, including easing restrictions on the development approach and subsidising such projects. The analytical results in Zone B indicated that direct administrative action can help solve problems by redeveloping and reviewing management methods for pedestrian paths. We consider that this technology is also available to examine which solution approaches are in line with policies targeted by the public administration, via comparisons in the same unit.

5. Prospects and Challenges

Utilising the technology introduced in this report can clarify those for whom the greenery will be effective and the identity of the maintenance and management entities tending such spaces by examining the urban level. With this in mind, we can adopt a multifaceted approach to evaluate the measures and decide whether 'we should value the working environment', ‘we should be conscious of the landscape designed with tourism demand in mind’ or ‘we should develop a resident-friendly environment’ under a common criterion of improving wellbeing. Moreover, this can be useful data to help plan the allocation of greenery more effectively. City dwellers will be able to choose wider-ranging activities to feel nature and greenery in their daily lives, while urban planners will be able to implement effective and more walkable urban designs based on greenery, including preferentially planting trees in high-traffic streets or attracting pedestrian flow by planting trees. We also consider that aggregated data on CGSET can be included in an effective master data set for comparing urban structure among cities and policy-making.

In Japan, more than 70 percent of the population inhabits densely inhabited districts (DIDs) already ahead of the rest of the world, which accounts for only 3.7 percent of its land area. Clarifying the actual state of greenery in each city can help when it comes to evaluating urban greening technologies, such as creating greenery that is accessible and easy to interact with as well as providing important data to the world. We would like to develop GAI maps for all DID nationwide, with the cooperation of the Task Force on Climate-related Financial Disclosure (TCFD), the Task Force on Nature-related Financial Disclosure (TNFD), companies and organisations striving to contribute to society through sustainable development goals (SDGs) and public administration from now on.

In this study, the GVI of the green spaces was set at 30 percent, assuming minimal planting. In this regard, we see the need to boost the accuracy of the status of urban greenery. Leveraging GSV information on the surrounding area alongside estimations from aerial photographs and park floor plans and actual measurements using 360-degree photography, etc.[25] can be effective for that purpose. In addition, the GVI of 30 percent is a value that can be reached in green spaces when the ground surface, which corresponds to the downward direction (ground), is covered with grass or other ground cover, even if the upward direction (sky) is not covered with greenery. When determining tree canopy coverage, we infer that GVI needs to be set at around 35-40 percent when identifying GAI. Accordingly, GVI assessment remains a future issue.

Additional Notes and References

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