ASSESSING CITY GREENNESS USING TREE CANOPY COVER: THE CASE OF YOGYAKARTA, INDONESIA

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ABSTRACT. The study aims to measure the greenness of an Indonesia city using tree canopy cover data. Rapid physical development brings impacts to the loss of urban trees, which leads to the increase of flooding risk, local temperature and pollution level. To address the issues, a baseline assessment of urban tree canopy existence is necessary as inputs for effective urban environmental management policies. The methods used in this research include 1) remote sensing and spatial analysis, and 2) simple quantitative analysis. Furthermore, three indicators are used in assessing the greenness, including 1) size of the canopy, 2) canopy cover percentage, and 3) canopy per capita. The results found that the city of Yogyakarta has a low level of greenness based on the canopy size in which covers only 467.37 ha or 14.38% of the total area. The second finding is Yogyakarta has an unequal distribution of canopy cover percentage in each district (kecamatan). The third finding is Yogyakarta City has a canopy per capita rate of 10.93 sg m/person. This number is below the UN recommendation of 15sg m / person. It indicates that residents have poor access to urban greenery. Additionally, the article discusses that the three indicators used have strength and weakness in measuring the level of greenness. Therefore, the assessment objectives must be taken into account. We recommend the use of each indicator as follows: 1) the canopy size is used as an initial inventory of the existence and distribution of the canopy, 2) the canopy cover percentage canopy percentage for measuring and comparing the level of greenness spatially and visually between areas, 3) the canopy per capita is used to measure the possibility of access and interaction of residents with the presence of a tree canopy. Cities' authority can use the information to measure the achievement of SDGs number 11, 13, or 15.

KEY WORDS: canopy cover; canopy per capita; city greenness; tree canopy; urban trees

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INTRODUCTION

The trees that live in urban areas, which are often called urban trees, provide essential benefits for the sustainability of the built environment. In urban areas with predominated impervious surfaces such as buildings and full of vehicle smoke pollution, some problems may appear including flooding, poor air guality, and hot local climate. Urban trees can provide ecosystem services to regulate those impacts and balance the environment, such as by absorbing stormwater run-off to reduce the risk of flooding (Y. Chen & Borelli 2016; Farrugia, Hudson, & McCulloch 2013; Pappalardo, La Rosa, Campisano, & La Greca 2017), reducing air pollution (Ferranti, MacKenzie, Ashworth, & Hewitt 2019; Martin, Chappelka, Loewenstein, & Keever 2012) and moderating local climate (Ali & Patnaik 2019; X. Chen et al. 2019; Norton et al. 2015; Zhou, Wang, & Cadenasso 2017). Besides, the existence of urban trees can also mitigate climate change in cities because of trees' ability to absorb carbon emissions (McGovern & Pasher 2016; Russo et al. 2014; Tang, Chen, & Zhao 2016). The existence of trees also provides space for biodiversity to live in (Aronson et al. 2017; Fineschi & Loreto 2020; Parmehr, Amati, Taylor, &

Livesley 2016; Trees & Design Action Group 2014). In the context of human and natural interactions, the presence of urban trees also positively influence residents' well-being and health (Fineschi & Loreto 2020; Soga & Gaston 2020; Ulmer et al. 2016). Accordingly, Sustainable Development Goals (SDGs) see urban trees as a significant aspect to achieve at least 3 goals which are Goal 11: Resilient and Sustainable cities, Goal 13: Climate Action, and Goal 15: Life on Land (Turner–Skoff & Cavender 2019; United Nations 2019).

Rapid physical development happening in cities often results in the loss of trees (Brunner & Cozens 2013; Guo, Morgenroth & Conway 2018; Guo, Morgenroth, Conway & Xu 2019; Nowak & Greenfield 2018). The continued impact of the urban trees and its canopy loss will lead to reduced ecosystem services provided by trees for cities (Elmes et al. 2017; Riley & Gardiner 2020). It means that environmental impacts are likely to happen more frequently in cities due to urban trees loss, such as urban heat island, flooding, and higher pollution. Awareness and concern for urban trees encourage urban environmental policies to maintain the existence of trees and tree canopies and try to raise their quantities and qualities (City of Melbourne 2012; Lavy & Hagelman 2017, 2019; Martin et al. 2012; Papastavrou 2019; Phelan, Hurley, & Bush 2019). Thus, to formulate better policies regarding urban trees management, cities need baseline information on urban tree canopy to (Intasen, Hauer, Werner, & Larsen 2017; McGee, Day, Wynne, & White 2012; Parmehr et al. 2016).

The purpose of this research is to measure the greenness of an Indonesia city using tree canopy cover data. Tree canopy is often used as a proxy to measure the level of greenness of an area (Ellis & Mathews 2019; Nowak & Greenfield 2018; Riley & Gardiner 2020). The article contributes to the literature of urban tree canopy management and planning by utilising three indicators: 1) canopy size for assessing the existence of tree canopy, 2) the canopy cover percentage for assessing distribution and equality of tree canopy, and 3) the number of canopy per capita as a proxy for assessing the accessibility of residents to interact with nature.

MATERIALS AND METHODS

Yogyakarta was chosen to be the case study in this research because it is one of the Indonesian cities with a fast growth rate. Yogyakarta is the capital of the Yogyakarta Special Region. The physical size of Yogyakarta is 3,249.31 Ha. The total population of Yogyakarta City in 2018 was 427,498 with a density of 131.57 persons / Ha. The population growth in Yogyakarta City is at an average of 1.14% per year based on 2016-2019 data. Yogyakarta has 14 districts with various sizes. The development of Yogyakarta City is considered rapid and has caused several environmental impacts. A study explained that the level of air pollution in Yogyakarta City is increasing due to development activities (Saptutyningsih & Ma'ruf 2015). Another research revealed that an urban heat island has occurred in several areas in the city of Yogyakarta as a result of the intensification of built elements along with the decline of natural elements in thea city (Husna, Fawzi & Nur 2018). Thus, our research argues that a solution to overcome the issues is to maintain and increase the existence of urban trees, because they provide ecosystem services such as pollution removal (Ferranti et al. 2019; Martin et al. 2012), moderation of the local climate (Ali & Patnaik 2019; X. Chen et al. 2019;

Farrugia et al. 2013) and other beneficial services. Based on this background, Yogyakarta City is an appropriate case study for the research.

The research method used is a combination of: (1) Satellite Imagery Processing and Spatial Analysis, and (2) Simple Quantitative Analysis. The methods are described below.

Satellite Imagery Processing and Spatial Analysis

The method used to obtain tree canopy data is through a high-resolution satellite imagery processing. The higher the resolution of an image, the more detailed and accurate the quality of the processing results (Godinho, Guiomar, & Gil 2018; McGee et al. 2012; Parmehr et al. 2016). Tree canopy data are generated from high-resolution satellite imagery with a spatial resolution of 0.44 m. Images with this resolution can provide sharp and clear images so that they are suitable for use as the materials for identifying urban tree canopies. Furthermore, the image is processed using the Envi Map application. The result of the identification of the canopy is a raster format map which is then converted into polygon shapefile format.

We apply a multi-spectral classification with a supervised classification analysis type as well as a maximum likelihood feature. This technique is effective and straightforward in identifying tree canopies in large-scale areas such as cities or wider (Bravo-Bello, Martinez-Trinidad, Valdez-Lazalde, Romero-Sanchez & Martinez-Trinidad 2020; Ossola & Hopton 2018). Moreover, the classes used in this classification include tree canopies, grass, open land, buildings, roads, and bodies of water. From the identification results, then the tree canopy polygons are separated for further analysis, the illustration of the tree canopy identification results can be seen in Figure 1. below.

Furthermore, spatial analysis is applied to calculate the size and the distribution of tree canopy according to district administrative boundaries. The spatial analysis used is simple, i.e. 1) 'intersect' between tree canopy polygons and district administrative boundaries, 2) 'calculate geometry' to obtain the size of tree canopy per district. The results of this spatial analysis were used in the second step, which is simple quantitative analysis.

0

50

100 m



0 100 200 m

Fig. 1. Illustration of Canopy Identification Method

Simple Quantitative Analysis

The simple quantitative analysis carried out includes 1) calculating the canopy cover percentage in the district area, and 2) calculating the canopy per capita for each district to assess its sufficiency based on the UN standard of 15 sqm/ person.

The canopy cover percentage is used to compare canopy cover in different boundary sizes (Campagnaro, Sitzia, Cambria, & Semenzato 2019) such as cities, sub-districts / suburbs, even neighbourhoods. The smaller the canopy cover percentage in an area means that there is less surface covered by tree canopy, which results in a lower greenness level (Seiferling, Naik, Ratti, & Proulx 2017). This condition has the same consequences for the ecosystem services that trees can provide, the smaller the canopy cover percentage; as a result, the smaller the ecosystem services provided by urban trees (McGovern & Pasher 2016). Then, to calculate the rate of canopy cover in the area, a simple formula is used:

%Can = [CanS (Ha) / Area (Ha)] x 100

%Can : percentage of canopy for each district CanS (Ha) : tree canopy size in hectares within the districts Area (Ha) : district size in hectares

The second indicator used is canopy per capita, which is a proxy used to measure the likelihood of residents access to natural components such as trees (UN HABITAT 2016). The literature states that the interaction between humans and nature is important due to various benefits such as maintaining the mental and physical health of city residents (Fineschi & Loreto 2020; Greene, Robinson & Millward 2018; Soga & Gaston 2020). Rest on this concept, the article argues that the greater the number of canopy per capita, the more likely it is for the public to access and gain socio-cultural benefits from urban trees. To calculate the canopy size per capita for each district, the following formula is used (UN HABITAT 2016):

Can/Cap = [CanS (sqm) / Pop]

Can/Cap : canopy per capita for each district CanS (sqm) : tree canopy sizes in sqm within district Pop : total population per district

The study also estimates potential carbon sequestration per year and total potential carbon storage of canopy. To estimate potential carbon sequestration and storage of urban tree canopy, we follow numbers of carbon sequestration and storage of urban trees from a previous study (Nowak, Greenfield, Hoehn, & Lapoint 2013). The previous study take U.S. cities as case for their research. They found that the net carbon sequestration of urban trees is 0.226 kg / m² / year and the total carbon storage is 7.69 kg / m². Then, the following formula are used:

CarbonSeq = Netseq x CanS (sqm)

where, CarbonSeq : estimated potential carbon sequestration of urban tree canopy per year Netseq : 0.266 kg / m^2 / year CanS (sqm) : tree canopy sizes in sqm within district and

CarbonStor = Stor x CanS (sqm)

CarbonStor : estimated potential carbon sequestration of urban tree canopy in total Stor : 7.69 kg / m^2 CanS (sqm) : tree canopy sizes in sqm within the district

It is important to note that the estimation in this study is not a direct measurement. It aims to illustrate rough estimation of urban tree canopy potential to support climate change mitigation. For this reason, further estimation with a more sophisticated method may be needed.

RESULTS

The research used three indicators to measure the level of the greenness of a city and its distribution between districts. The first is the canopy size. The canopy size is the most basic data generated from the spatial analysis. The second information is the canopy cover percentage that compares the canopy size to districts size. The third information is the canopy area per capita calculated by dividing the canopy size by the number of people living in the area. The findings of each information are described as follows.

Canopy Size

The analysis results show that the total canopy size of Yogyakarta is 467.37 Ha. Also, when using actual canopy size data in each district, the tree canopy size distribution ranges from 6.46 Ha - 134.19 Ha. Umbulharjo is the district with the widest canopy (134.19 ha) and Pakualaman hase the smallest canopy size (6.46 ha). The detailed pattern of canopy size distribution per district can be seen in Table 2. Of the 14 districts, the average number of canopy size is 33.38 Ha, and the mean value is 21.92 Ha. The size of each district relates to the size of the district boundaries. Based on the size of the district, Umbulharjo is the largest district (812 hectares), and Pakualaman is the district with the smallest size (63 hectares). The rankings that appear in canopy size have a similarity to the order of district boundaries size (See Figure 2 for a graph illustrating this pattern). Therefore, it was concluded that canopy size data could provide an initial depiction of the existence and distribution of tree canopies. Still, the information cannot be the only benchmark in assessing the level of the greenness of an area. Consequently, further information is needed, such as the percentage of canopy and canopy cover per capita.

| No. | Data | Function | Sources | |
|-----|-----------------------------------|---|---|--|
| 1 | Yogyakarta Satellite Imagery 2018 | For classifying and identifying tree canopy. The classification results are then converted into tree canopy polygons. | Yogyakarta Land and Spatial Planning Board | |
| 2 | District Administrative Boundary | As a unit of analysis and visualisation | | |
| 3 | The population of 2018* | Calculation of population density and canopy per capita | | |
| 4 | District area size | Estimation of population density and canopy cover per district | (Statistics Board) | |

Table 1. Data and Sources



Fig. 2. Canopy size and Canopy Cover Percentage

Canopy Cover Percentage

The canopy cover percentage is obtained by dividing the canopy size by the size of an area (district). The canopy cover percentage in Yogyakarta City currently only reaches 14.38% or 467.37 Ha of the total size of Yogyakarta City of 3,249.31 Ha. If we compare the canopy cover percentage in Yogyakarta with several noteworthy green cities in the world (Liu & Jensen 2018), the canopy cover in Yogyakarta is relatively low. For example, Singapore has a canopy cover percentage of 29.3% and Geneva has 21.4% (data source: Treepedia; methods used see (Li et al. 2015; Seiferling et al. 2017)). There is also Melbourne with an actual canopy cover rate of 22% and a target of increasing the canopy of up to 40% by 2040 (City of Melbourne 2012). A brief look at these cities provides an overview of the direction of the tree canopy policy that Yogyakarta City needs to formulate, namely the protection and addition of urban tree canopies.

Next is the canopy cover percentage at the district level. The results of the calculation of the canopy cover percentage in the districts of Yogyakarta ranged from 9.27% - 17.38% with an average number of 12.70% (see Table 2). Based on the canopy cover percentage, there is a similar trend even though there has been a slight change in the ranks (see Figure 2 for a graph that illustrates it). The district with the most extensive canopy cover is Kotagede with 17.38% covering the area. Umbulharjo, which has the largest canopy size, was in second place for the canopy cover percentage with 16.53%.

The district with the lowest rate of canopy cover is Danurejan with 9.27%. It is observed that the level of greenness in the city of Yogyakarta is not evenly distributed to each district (see Figure 4).

Canopy per Capita

Using population data in 2018, the canopy per capita in Yogyakarta City is 10.93 sqm/person. This number is still below the standard set by the UN, which is 15 sqm/person (UN HABITAT, 2016) hence requiring an escalation of about 4.07 sqm/person (See Figure 3). If we look at the data at the district level, the rate of canopy per capita in Yogyakarta ranges from 4.69 sqm/person - 14.45 sqm/person. This means that all districts in Yogyakarta City have canopy per capita number below the UN recommendation. In Figure 3, a graph of the distribution of canopy per capita for each district is presented as well as the additional gaps that can be potentially added. The district with the lowest canopy per capita was Ngampilan (4.69 sqm/person), and the district with the most extensive canopy per capita was Umbulharjo (14.45 sqm/person). The spatial distribution pattern can be seen on the map contained in Figure 4. Moreover, based on the data from 14 districts, it is obtained an average value of 9.29 sqm/person and a mean value of 8.10 sqm/person. All of the information indicates that there is still a lack of canopy size in Yogyakarta City to facilitate access and interactions of residents with natural components such as trees.



Fig. 3. Canopy per Capita and the Gap

Potential Carbon Sequestration and Storage

The study also analyse a rough estimation of carbon sequestration and storage of urban trees. The finding simply shows that the larger the size of canopy cover, the larger the potential number of carbon absrobed and stored by urban trees. Based on the estimation, the largest potential carbon sequestration is in Umbulharjo (303.45 t C / year) and the lowest potential carbon storage is in Pakualaman (14.61 t C / year). The total city-level potential carbon sequestration is 1,056.25 t C / year, while the average carbon sequestration is 75.45 t C / year and the median is 49.55 t C / year. In addition, city-level potential carbon storage is 35,940.44 t C while the average is 2,567.17 t C and the median is 1,685.90 t C. Table 2 column I and J provide detailed estimation of carbon sequestration and storage for all districts.

DISCUSSION

Strengths and Weaknesses of Indicators

This research uses three different types of information to measure the greenness level of a city, namely the canopy size, the canopy cover percentage, and canopy per capita. Cities authority may use the information as one of indicators to measure achievement of SDGs, especially for Goals 11, 13, and 15 (Turner–Skoff & Cavender 2019). The three types of information have their respective strengths and weaknesses in measuring the greenness of a city. The strengths and weaknesses identified by the authors are presented in Table 3.

Policy Implications

The article discusses policy recommendations into two parts: the first part is the general policy implications for cities in Indonesia; the second part is the policy implications that specifically targets Yogyakarta City as the case study used in this research. The first is related to policy recommendations for cities in Indonesia. The results of this research indicate that Yogyakarta City has a relatively low level of greenness based on information on canopy size, canopy cover percentage, and canopy per capita. This condition is likely to occur in other Indonesian cities (Ramdhoni, Rushayati & Prasetyo 2016). In Indonesia, the current green infrastructure policy framework only regulates mandatory size for green open space in urban areas. It mandates urban areas to have at least 30% open space, consisting of 20% public open space and 10% private open space. Additionally, in terms of urban trees, there is a policy guideline that helps local authorities to increase urban greeneries with various green open space design and planning strategies. The guideline, however, does not integrate the urban tree preservation with other urban development permit schemes. In addition, the absence of urban tree management policy plays a significant role in the decreased numbers of urban trees (Guo et al. 2019; Nowak & Greenfield 2018; Phelan et al. 2019). This article recommends a policy framework for better urban trees planning and management in Indonesian cities that integrate urban trees preservation, technology, and permit schemes (See Figure 5).

Accordingly, the first recommendation in this research is that there is a need for similar studies to assesses the

| A | В | С | D | E | F | G | Н | 1 | J |
|----------------|-------------------|----------------------|----------------------------|---------------------|----------------------|--------------------------------------|---|--|---|
| District | Area Size (ha) | Population (2018) | Population Density / ha | Canopy size (ha) | Canopy size (sqm) | Canopy cover percentage (%) | Canopy per capita (sqm/ person) | Potential Carbon Sequestration (t C / year) | Potential Carbon Storage (t C) |
| Formula | Area | Рор | Pop/Area | CanS (Ha) | CanS (sqm) | CanS / Area x 100 | CanS (sqm) / Pop | netseq x CanS (sqm) | Stor x CanS (sqm) |
| Ngampilan | 82.00 | 17,117 | 208.74 | 8.03 | 80,346.46 | 9.80% | 4.69 | 18.16 | 617.86 |
| Gedong Tengen | 96.00 | 18,546 | 193.19 | 9.74 | 97,399.06 | 10.15% | 5.25 | 22.01 | 749.00 |
| Danurejan | 110.31 | 19,223 | 174.26 | 10.22 | 102,207.24 | 9.27% | 5.32 | 23.10 | 785.97 |
| Pakualaman | 63.00 | 9,336 | 148.19 | 6.46 | 64,634.69 | 10.26% | 6.92 | 14.61 | 497.04 |
| Kraton | 140.00 | 17,575 | 125.54 | 14.19 | 141,870.49 | 10.13% | 8.07 | 32.06 | 1,090.98 |
| Jetis | 170.00 | 24,036 | 141.39 | 18.81 | 188,123.27 | 11.07% | 7.83 | 42.52 | 1,446.67 |
| Gondomanan | 112.00 | 13,781 | 123.04 | 10.82 | 108,176.14 | 9.66% | 7.85 | 24.45 | 831.87 |
| Mergangsan | 231.00 | 30,836 | 133.49 | 25.03 | 250,342.07 | 10.84% | 8.12 | 56.58 | 1,925.13 |
| Wirobrajan | 176.00 | 26,134 | 148.49 | 26.98 | 269,817.42 | 15.33% | 10.32 | 60.98 | 2,074.90 |
| Mantrijeron | 261.00 | 33,688 | 129.07 | 40.88 | 408,802.07 | 15.66% | 12.13 | 92.39 | 3,143.69 |
| Tegalrejo | 291.00 | 38,691 | 132.96 | 47.41 | 474,066.63 | 16.29% | 12.25 | 107.14 | 3,645.57 |
| Kotagede | 307.00 | 37,937 | 123.57 | 53.37 | 533,698.02 | 17.38% | 14.07 | 120.62 | 4,104.14 |
| Umbulharjo | 812.00 | 92,867 | 114.37 | 134.19 | 1,341,925.62 | 16.53% | 14.45 | 303.28 | 10,319.41 |
| Gondokusuman | 398.00 | 47,731 | 119.93 | 61.23 | 612,250.24 | 15.38% | 12.83 | 138.37 | 4,708.20 |
| Average (Mean) | | | | 33.38 | 333,832.82 | 12.70% | 9.29 | 75.45 | 2,567.17 |
| Median | | | | 21.92 | 219,232.67 | 10.95% | 8.10 | 49.55 | 1,685.90 |
| City Level | 3 249 31 | 427 498 00 | 131 57 | 467 37 | 4 673 659 42 | 14 38% | 10.93 | 1 056 25 | 35 940 44 |

Table 2. Canopy Distribution in Yogyakarta City



Fig. 4. (a) Population density; (b) Sizes of the districts; (c) Actual tree canopy polygons; (d) Tree canopy size per districts; (e) Canopy per capita; (f) Canopy cover percentage. Details in numbers are presented in Table 2

existence of urban tree canopy in Indonesian cities. baseline information regarding the presence of urban trees is required to formulate more effective policies for managing urban trees and its ecosystem services (Intasen et al. 2017; McGee et al. 2012; Parmehr et al. 2016) that can contribute to create more sustainable Indonesian cities. Further studies on urban trees in Indonesian cities may also add more detailed information such as the types, losses, gain, key ecosystem services, even health status of the trees.

The second recommendation is that urban trees should be put as the priority development programs and activities. It aims to increase the level of the greenness of cities in Indonesia asl well as to achieve SDGs Goal 11, 13, and 15. This recommendation can be adopted by agencies in charge of the environment and open space sector. Accordingly, business as usual policies related to urban trees need to be transformed into more innovative approaches to preserve and increase the existence of urban trees (Trees & Design Action Group 2012, 2014). For example, by integrating the control and conservation of urban trees with zoning regulations (Davey Resource Group 2015; Phelan et al. 2019), construction permits (Guo et al. 2019; Morgenroth, O'Neil-Dunne, & Apiolaza 2017), and development permits as exemplified in many other cities in the world (Hilbert et al. 2019; Lavy & Hagelman 2017, 2019). At the same time, programs and activities to grow more trees also need to be implemented in a visionary and measurable way. The City of Melbourne, for instance, created an 'Urban Forest

Strategy' which includes a series of long-term oriented programs and actions accompanied by regular monitoring and evaluation (City of Melbourne 2012). One of their targets is to achieve 40% canopy cover percentage in public realms which must be completed by 2040 along with various annual programs and activities to achieve this target. Another example comes from Singapore that plans urban forestry rehabilitation that covers every scale and land use types such as protected natural area, streetscapes, parks, even vacant lands (Davison 2005) and applying the biophilic concept to their urban environments (Singapore National Parks Board, accessed on August 2020)

The third recommendation is an engagement of stakeholders which is also an essential aspect of urban tree management (Brunner & Cozens 2013; Drillet et al. 2020; Papastavrou 2019; Trees & Design Action Group 2014). As explained above that protection of trees needs to be integrated into land-use permit schemes such as zoning, construction and development permits. As every stakeholders have roles in protecting and even increasing the number of urban trees, it is necessary to involve a variety of stakeholders. Those stakeholders include government as the policymaker, regulator, and license issuer (Lavy & Hagelman 2019; van der Jagt & Lawrence 2019), contractors and developers as parties carrying out physical construction (Guo et al. 2018; Morgenroth et al. 2017; Phelan et al. 2019), as well as city residents as private land owners (Conway 2016; Davis & Jones 2014).

The implications of the second policy are specifically addressed for the City of Yogyakarta. First, this research finds a pattern that the level of greenness in the city centre area is relatively lower, as indicated by the canopy size and the lower percentage of canopy cover. They are Ngampilan, Danurejan, Pakualaman, Keraton, Gedongtengen, Gondomanan (see Figure 4 and Table 2 for details). These districts have lower tree canopy due to rapid physical development and population growth that led to urban trees removal. The population density map (Figure 4 (a)) demonstrates that these areas have relatively higher population density that other districts. According to the existing land use, the areas are also dominated by built-up uses such as housing, commercial and services, as well as industries. Besides, an absence of urban tree demolition permits in the city is one of the potential causes of urban trees shortage.

Thus, the local authority can prioritise those areas for trees planting sites, to increase canopy size and the percentage of tree canopy cover. As stated in a previous study that increasing the canopy size and canopy cover percentage can increase aesthetics (Conway 2016), while simultaneouslyproviding more ecosystem services to the city. Those ecosystem services include reducing pollution (Ferranti et al. 2019; Martin et al. 2012), providing thermal comfort (Ali & Patnaik 2019; X. Chen et al. 2019; Farrugia et al. 2013), reducing the potential for flooding (Y. Chen & Borelli 2016; Farrugia et al. 2013; Pappalardo et al. 2017), even absorbing carbon and helping to mitigate climate change (McGovern & Pasher 2016; Russo et al. 2014; Tang et al. 2016).

In this second part, the findings show that all districts in Yogyakarta City have a canopy per capita below the UN recommendation rate of 15 sgm/person. This condition indicates the low likelihood of residents interacting with the urban green component. A city should ideally be able to accommodate its residents to interact with nature. With a relatively dynamic population and an increasing trend, keeping pace with population growth and development activities with urban tree planting (to grow the canopy per capita) is a strategic policy recommendation for the City of Yogyakarta. The priority of adding trees can be directed at districts with a small canopy per capita (for example, below 10 sqm/person) so city residents can have more even access to tree canopies. The second priority is to grow the number of canopy per capita in districts that are already close to the UN recommendation rate. That way the distribution of the canopy per capita will be more even. The even distribution of the canopy provides equal access for residents to interact with urban trees. The interaction of city residents with environmental elements such as trees can maintain the mental and physical health of residents (Fineschi & Loreto 2020; Greene et al. 2018; Soga & Gaston 2020). The interaction between residents and trees can also enhance understanding and knowledge about environmental conservation, especially in the protection of urban trees (Davis & Jones 2014).

Limitations and Potential for Future Research

This research acknowledges several weaknesses that can be improved in further research. Firstly, as by aiming





Fig. 5. Urban Trees Planning and Management Policy Framework

| Type of Information | Data Needed | Strength | Weakness | Recommended Usage |
|--|---|---|---|--|
| Canopy size | Only canopy size | Provides preliminary information on the extent and distribution of canopy displayed in data by area (district or smaller) | Using only the canopy size can cause bias in assessing the level of greenness because the canopy size can be affected by the size of the area | As an initial data inventory for further analysis |
| Canopy cover percentage | 1. Canopy size 2. Area / Boundary Size | The percentage unit allows a fairer way to compate greenery levels between areas | Data characteristics tend to be static, especially in the size component. Static data potentially influences business-as-usual policy formulation | To compare the level of greenness between areas (such as districts, sub- districts, neighbourhoods) As input for regulating ecosystem services, such as local climate moderation (such as thermal comfort / reducing urban heat island) and stormwater run-off regulation |
| Canopy Per capita (sqm/person) | 1. Canopy size 2. Total Population | Describes the socio- environmental aspects and serves as an approach in measuring the accessibility of urban residents to interact with the natural components of the city (trees) | With its dynamic characteristics especially on the components of the population, the indicator requires an adjustment of the target every year. Assessment activities also need to be an annual routine | To measure the accessibility of residents' interactions with natural components, especially urban trees As an approach for analysis related to cultural ecosystem services, such as recreation and inspiration |
| Potential Carbon Sequestration and Storage | Canopy size Carbon sequestration ability Carbon storage ability For direct measurement, more data may be needed such as tree species, size, old, etc | Describes the climate change mitigation potential of urban trees to further influence urban tree preservation and urban environmental policies. | Direct measurement of carbon sequestration and storage of urban trees need more sophisticated methods, detailed data, and larger samples. | To understand the current state of urban trees' ability in mitigating climate crisis As the baseline data for carbon offset scheme |

Table 3. Weaknesses, Strengths, and Recommendations for Usage

for a baseline assessment, this research does not use spatio-temporal data. To get temporal data of canopy, high-resolution satellite images from the past years are necessary (Ellis & Mathews 2019). By using temporal data, the information obtained can include the dynamics of the presence of the canopy (Ossola & Hopton 2018). In other words, the research can identify information regarding the gains and losses of the canopy and the area where canopy gains and losses occur (Davey Resource Group 2015; Ellis & Mathews 2019; McGovern & Pasher 2016). Besides, by using spatio-temporal data, the loss of ecosystem services resulting from declined tree canopy size can also be estimated (McGovern & Pasher 2016; Riley & Gardiner 2020). By estimating ecosystem services, strategies to protect or even increase the number of trees in urban areas can be formulated effectively based on evidence (evidencebased policy). Secondly, cross-sectoral analysis is also recommended for future research in urban tree canopy field, especially in Indonesian cities context. For instance, future research may link canopy cover data with sociodemographic characteristics (Hostetler, Rogan, Martin, Delauer, & Oneil-Dunne 2013; Lavy & Hagelman 2017), with development policies, as well as land-use dynamics (Davey Resource Group 2015; Ellis & Mathews 2019; Phelan et al. 2019). Future research can also utilise spatial modelling to identify a potential area for tree planting. Possible methods include multi-criteria analysis based on remote sensing

and GIS (geographic information systems)(Bravo-Bello et al. 2020; Davey Resource Group 2015). Lastly, future research may also combine tree canopy assessment and more sophisticated methods in directly estimating potential carbon sequestration and carbon storage (McGovern & Pasher 2016) in order to assist cities in taking a role in mitigating climate crisis (Bayulken, Huisingh, & Fisher 2021; Frantzeskaki 2019; Petri, Wilson, & Koeser 2019).

CONCLUSIONS

This research has measured the level of the greenness of an Indonesian city by using the presence and distribution of urban tree canopy. The methods used in this research are remote sensing, spatial analysis, and simple quantitative analysis. The spatial distribution of the tree canopy has been identified identified and analysed. From the urban tree canopy data, we present three types of information, namely: 1) canopy size for assessing the existence of tree canopy, 2) the canopy cover percentage for assessing distribution and equality of tree canopy, and 3) the number of canopy per capita as a proxy for assessing the accessibility of residents to interact with nature.

The findings show that the total canopy size of the city of Yogyakarta is only 467.37 hectares. The tree canopy size distribution per district ranges from 6.46 Ha - 134.19 Ha. Of the 14 districts, the average canopy size number is 33.38

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Ha, and the median value is 21.92 Ha. Next, the percentage of canopy cover in Yogyakarta is only 14.38% covering the area of the city. If we look at the districts level, the canopy cover percentage in districts in Yogyakarta ranges from 9.27% -17.38% of the area. This number is relatively lower compared to green cities in the world, such as Singapore and Melbourne. Additionally, this research found that the number of canopy per capita in Yogyakarta City is still below the UN recommendation rate of 15 sqm/person. The canopy per capita rates in the Yogyakarta districts are only around 4.69 sqm/person - 14.45 sqm/person. These findings suggest that an integrated, visionary and measurable policy is needed to protect and to plant more trees in Yogyakarta strategically. Moreover, the three indicators used have strenghts and weaknesses in measuring the level of greenness. This research recommends the use

of each indicator as follows: 1) canopy size information as an initial data inventory for further analysis, 2) Canopy cover percentage to measure and compare the levels of greenness spatially and visually between areas, 3) Canopy per capita is recommended to measure the possibility of access and interaction of residents with the presence of tree canopies. Cities' authority can also use the information to measure the achievement of SDGs number 11, 13, or 15.

Finally, as a preliminary research this study proposes several recommended improvements for further research. First, following research may use temporal data to identify the dynamics of urban tree canopy from year to year. In addition, future studies may also utilise a more sophisticated spatial analysis such as multi-criteria site selection and modelling to identify new tree planting sites.

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