Canopy Interception Assessment of Urban Park Greenery: A Case Study of Ganesha Park, Bandung, Indonesia

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Abstract: Urban greenery provides enormous benefits that include flood regulation by intercepting rainfall before it evaporates, thus contributing to reducing runoff. Hydrologic modelling is often used to simulate floods, including runoff-generating processes in urban environments, based on raster data. However, the modelling outcomes heavily rely on image resolutions of the input data, particularly when the image contains mixed pixels. Laser-scanning technology has been widely used to assess three-dimensional plant morphology in more detail, including leaf characteristics. However, research on tree canopy interception based on Leaf Area Index retrieved from three-dimensional data is still limited. This paper addresses this existing gap in estimating the storage capacity of tree canopy using point cloud data from airborne laser scanners (ALS) and terrestrial laser scanners (TLS), and applying the Kristensen and Jensen method at Ganesha Park, Bandung, Indonesia. The outcomes show that all trees in the area can contribute to intercepting 54,83% of the total precipitation per day during heavy rainfall. It is suggested that this study can demonstrate the invaluable use of tree canopies in reducing runoff in an urban context.

Keywords: Canopy interception, point clouds, urban park

1 Introduction

This study assesses canopy interception in an urban park based on three-dimensional point cloud data. Canopy interception is often estimated using an evapotranspiration model adopted in hydrologic modelling (DHI 2007). As one of the main factors that influences rainfall interception, Leaf Area Index (HERBERT & FOWNES 1999) is defined as the area of one-sided leaves per unit of ground area (JOHN MONTEITH & UNSWORTH 1973), or "the total intercepting area per unit ground surface" (CHEN & BLACK 1992, 421). Raster-based hydrologic modelling uses a set of formulas to model the evapotranspiration process using the information of LAI from each pixel. Thus, the outcomes rely on the image resolutions of the input dataset. However, mixed pixels (e. g., vegetated and non-vegetated objects identified and shown within one pixel) are often found in satellite imagery with a coarse spatial resolution. The non-homogenous land cover information within a pixel leads to image misclassification (FOODY 2002). RANI et al. (2022) demonstrated how the issue of mixed pixels in satellite imagery, which is used to generate land cover maps, would influence further landscape analysis using these maps.

Methods to retrieve LAI consist of direct and indirect methods (BRÉDA, 2003). The direct techniques include harvesting, allometry and litter collection. Whereas indirect methods comprise various approaches, such as a gap of fraction measurement (WEISS et al. 2004),

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hemispherical image analysis (BASUKI, 2015), the estimation from Li-Cor LAI2000 plant canopy analyzer (MALHADO et al. 2009), and the assessment using the 3D data from LiDAR (HOSOI & OMASA, 2009; INDIRABAI et al. 2020; YANG et al. 2019; YOU et al. 2022).

The rapid development of laser-scanning technology has prompted substantial research on three-dimensional plant morphology in more detail. Although various studies have used point clouds to assess leaf characteristics, there are only limited studies on assessing canopy interception using point cloud data. A systematic review of the Scopus database shows that there are at least 194 studies conducted in 2005-early 2024 have used 3D point clouds to estimate LAI, but only one of them calculated canopy interception using the modelled LAI (MOSTAFA et al. 2022). The study was conducted based on the Community Land Model equation (SHENG & CAI, 2019) and there is a need to test other types of trees. In addition, a study that calculated the LAI of tree foliage retrieved by a terrestrial laser scanner (TLS) and measured throughfall has also been conducted by YANG et al. (2019). Therefore, this research intends to address the existing gap of study on estimating the canopy storage capacity of trees at a case study area based on the estimated LAI derived from point cloud data, which is collected using both TLS and airborne laser scanner (ALS). The two scanners capture data from below and above the tree canopies, providing the more complete and detailed point data.

The site study is located at Ganesha Park, Bandung, Indonesia. Ganesha Park (approx. 1,2 Ha) is located at the southern tip of the main campus of Institut Teknologi Bandung. The park, built in 1919, was designed with the concept of Indische Tropische Park (Indonesian tropical park) proposed by Bandoeng Vooruit. The design also incorporated the famous 18th-century Renaissance Garden style, characterised by the symmetric layout with elements of clipped hedges, parterres, stairways, and a water fountain. Arenga pinnata trees were originally planted along the eastern and western perimeter of the park. Whereas Casuarina junghuhniana had been mostly found on the northern side of the park (KUNTO, 1986), before they were mostly replaced by bushes. More trees, then, have been planted to provide large shading to the park users and activities. Currently, Filicium decipiens is the predominant tree species that was planted alongside pedestrian paths that run North-South, accentuating the symmetric park layout.

Ganesha Park has become one of the notable green spaces in Bandung. The park is also a part of the Ci Kapundung water catchment area, the fastest degrading watershed in Bandung Basin (HARYANTO et al. 2007). Urban green spaces provide ecosystem services for people that include flood regulation. Tree canopies in urban parks have the capacity to intercept a proportion of rainfall before it evaporates, while unbuilt areas absorb another that falls on the ground. Therefore, it is important to assess the potential of trees in the already scarce urban green spaces that contribute to reducing excessive runoff flowing into rivers and causing floods, in which laser-scanning technology can be utilized during the process. This study addresses the following research question: How can the point cloud data be used to estimate the canopy storage for each tree in the case study area? This paper illustrates the contribution of tree canopies at Ganesha Park identified by laser scanners to reducing runoff by intercepting a portion of rainfall.

2 Material and Methods

This study used point cloud data of Ganesha Park that was acquired using both an airborne laser scanner (ALS) and a terrestrial laser scanner (TLS) (Fig. 1). The TLS ranging resolution is 4 mm at a 10-m distance. Data preprocessing had been conducted for denoising and registration before the point clouds were used to generate segmentation of the ground surface. A MATLAB workflow was adopted to normalize the elevation, create a Canopy Height Model (CHM) and segment the individual trees (https://www.mathworks.com/help/lidar/ug/extraction-of-forest-metrics-and-individual-tree-attributes.html#responsive_offcanvas from The MathWorks, Inc. 2023), in which each process is described as follows. The elevation normalization process was conducted by eliminating duplicate points along the x- and y-axis and creating an interpolant to estimate ground at each point. Then, CHM was generated from the normalized elevation values. Cloud Compare was used to manually segment the trees and to retrieve the attributes of each tree (i. e., length and width of the tree canopy, and the tree height). A MATLAB syntax was used to identify the canopy leaves from each tree based on their colour, in which the number of points was then identified using Cloud Compare.

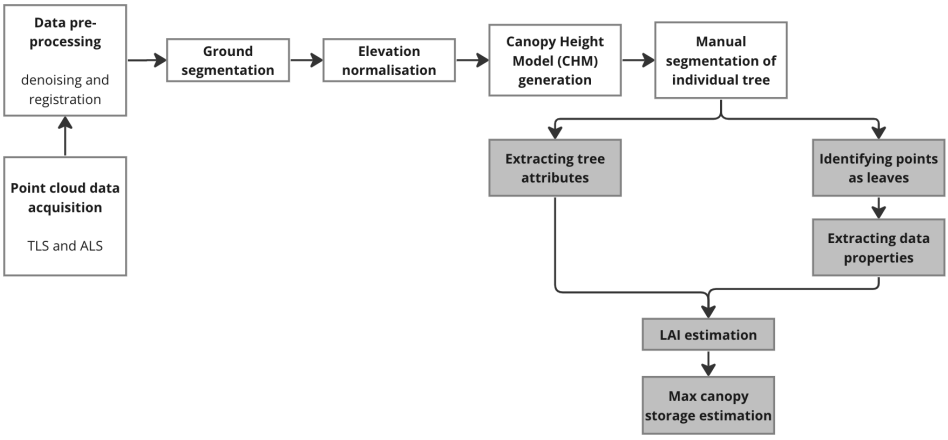

Fig. 1: Workflow for canopy storage estimation based on LiDAR data

The outcomes were used to estimate LAI for each tree using the point spatial density (PSD) algorithm from INDIRABAI et al. (2020) (Equation 1), where n_p is the number of points from the objects that were identified as leaves, d refers to point spacing, x_t, y_t, and z_t are the length, width, and height of the tree, respectively.

$$\text{Leaf Area Index (LAI)} = \frac{n_p d(x_t+y_t)}{x_t y_t}\left(\frac{1}{z_t}\right) \quad \text{(Equation 1)}$$

This study adopted the Kristensen and Jensen method (1975), which is primarily used in hydrologic modelling (DHI, 2007), to estimate the maximum canopy storage for each tree. The model assumes that canopy interception storage (I_{max}) should be filled before stem flow occurs. Different types of vegetation at each stage of development, which is characterized by the leaf area index (LAI), have a distinct I_{max} capacity. Equation 2 is the formula to compute

I_{max} that is used in MIKE SHE (https://www.mikepoweredbydhi.com/products/mike-she), a physically based hydrologic model developed by the Danish Hydraulic Institute (DHI). The estimation requires C_{int} or an interception coefficient that defines the interception storage capacity. The typical C_{int} value used in modelling is 0.05 mm, which can be determined through calibration (DHI 2007). This study adopted this typical value to estimate the maximum canopy storage which is limited to the utilization of the I_{max} equation that is often employed at the initial stage of the MIKE SHE simulation (i. e., before calibration). However, there were neither hydrologic modelling nor the rainfall and throughfall measurements (YANG et al. 2019) were conducted in this study. Therefore, the results from this process should be interpreted within this scope. The outcomes, then, were used to demonstrate how the current state of the tree canopy potentially intercepts one year of rainfall. Precipitation data from Dago Pakar meteorological station near the study area in 2018 was used in this research.

$$I_{max} = C_{int} \cdot LAI \quad \text{(Equation 2)}$$

3 Results

The 3D point imagery of the Ganesha Park and the samples of segmented trees retrieved from the ALS and TLS are shown in Figures 2 and 3, respectively. Many trees in the park are as old as 100 years. However, as designed according to the concept of tropical indische while incorporating Renaissance Garden style, these century-old trees appear not to be selected based on their shades, but the types that characterise tropical and renaissance images, such as palm, banana, and cypress. Nonetheless, based on data collection, more trees have been added to provide large shading to the park users and activities. There are 71 out of 144 recorded trees (or about 49,3 %) are higher than 15 metres tall, including the two highest trees of 52,38 metres and 53,39 metres, and 61 trees or about 42,4% are between 10 to 15 metres, while only 12 out 144 trees or about 8,3% are less than 10 metres height. Meanwhile, 18% of the total number of trees have canopies at least 15 metres wide. The data indicates that Ganesha Park is mostly occupied with mature trees that reach their tallest height and their fullest size canopy.

The LAI and maximum canopy interception from 144 trees in the park have been estimated using the PSD equation and the Kristensen and Jensen method, respectively. The potential canopy interception from all trees is 29,06 mm every time step. With the highest daily precipitation rate of 53mm/day (Figure 4), all tree canopies can catch 54,83% of total precipitation during heavy rainfall in 2018. Ten trees with the highest modelled LAI (Table 1) potentially intercept 6,44 mm of rainfall every time step or contribute to capturing approximately 12,15% of the total precipitation per day.

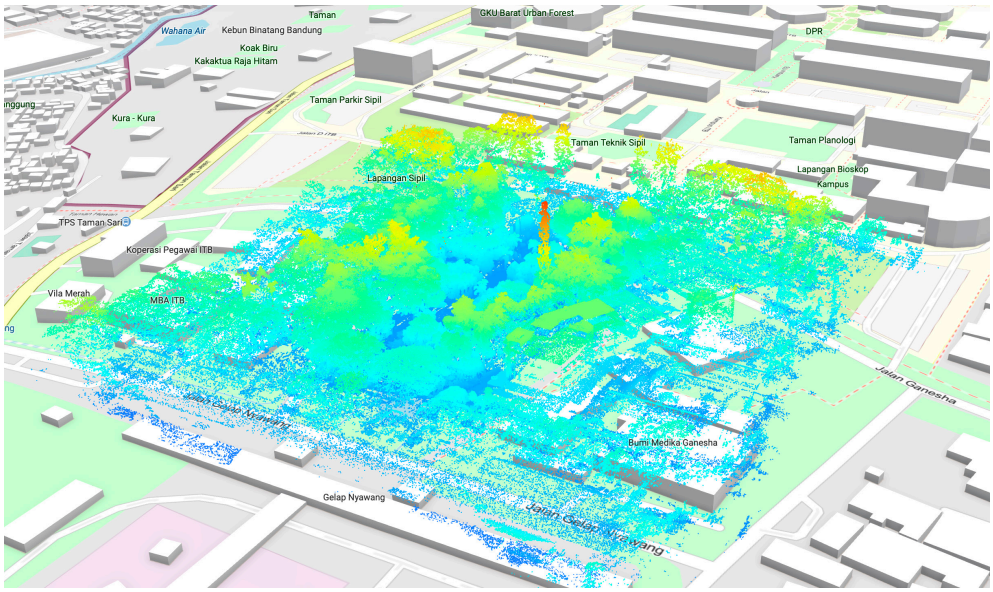

Fig. 2: Point clouds of Ganesha Park with ESRI Basemap from OpenStreetMap

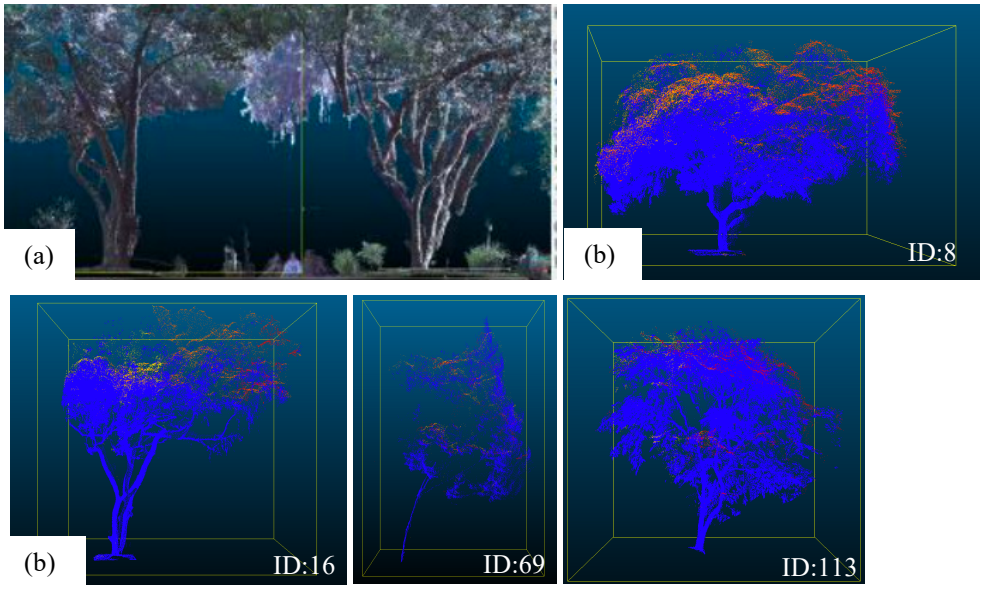

Fig. 3: Point data of (a) a cluster of trees, and (b) segmented trees with the highest LAI

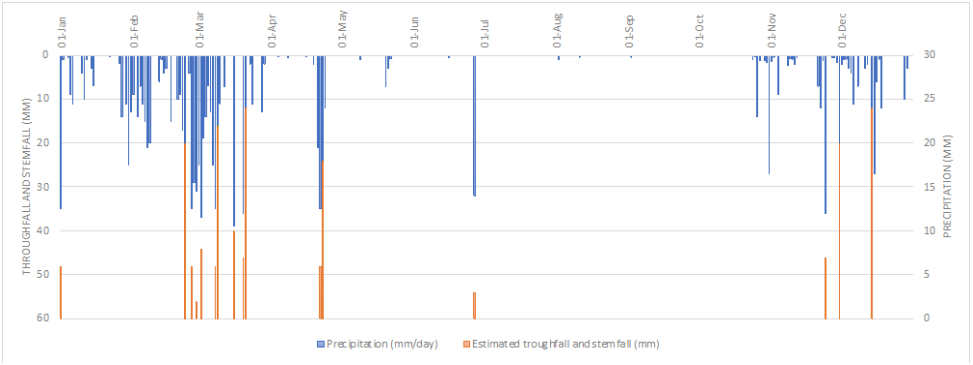

Fig. 4: Precipitation rate (mm/day) in 2018 and the estimated stemflow and throughfall

Table 1: Estimated LAI and canopy intercept for selected trees

TreeID	Num-ber of points	Tree-Height (m)	X (m)	Y (m)	Estimated LAI	Estimated canopy intercept
58	36251	10	3,81	3	11,27	0,56 mm
16	586816	12	12,00	11	11,41	0,57 mm
8	711599	10	15,31	14	11,49	0,57 mm
59	53526	10	3,56	4	12,06	0,60 mm
153	89398	8	7,19	5	12,11	0,61 mm
69	63749	9	5,69	4	12,43	0,62 mm
73	27768	10	4,06	2	12,64	0,63 mm
113	404786	9	9,38	12	13,35	0,67 mm
56	53875	9	4,75	3	14,85	0,74 mm
15	2420327	12	17,06	14	17,16	0,86 mm

4 Discussion

The 3D data from LiDAR technologies provide enormous possibilities for analysing spatial information and modelling. Spatial analysis using point cloud data is suitable for areas where existing data is lacking and also for projects that require more specific data (GIROT 2019). This study demonstrates how ALS and TLS can capture the canopy structure in 3D, allowing a further assessment of LAI could be conducted with a higher precision than with those using multispectral remote sensing and the radiative transfer model (LI et al. 2022). Both datasets captured by ALS and TLS have been merged to generate one integrated set of point cloud data. However, there were only six stations for retrieving the TLS data from the below tree canopy, thus they might not capture all the segments of trees, which has become the limitation of this study. BRÉDA (2003) argued that the indirect methods do not estimate the actual LAI because other canopy elements such as branches and stems are included in the assessment. In this study, a script was used to extract points identified as leaves from each tree, resulting in only the required point cloud data (e. g., leaves) being further used in the LAI estimation. Although the direct methods (e. g., destructive sampling) provide the true LAI values, the

application is not suitable for areas with tall trees (FANG et al. 2019), such as at the Ganesha Park. Future studies should include other methods to assess LAI (FANG et al. 2019), such as the use of a plant canopy analyzer and a gap of fraction measurement, and make a comparison of the outcomes when using different methods.

Both the acquisition of geographical data and the geo-processing are prone to uncertainty (ZHANG & GOODCHILD 2002), including the process of LAI estimation using ALS data (LI et al. 2022). In this study, a manual segmentation has been performed for all trees based on a field observation to identify the canopy structure, despite that many of them have their canopies overlapped with each other. The point spatial density (PSD) algorithm (INDIRABAI et al. 2020) that was applied to estimate LAI relies on the number of points captured for each tree. However, as mentioned above, there are possibilities that all parts of the tree foliage were not fully captured by both the ALS and TLS, and the manual segmentation might be insufficient to provide the perfect tree segments, thus impacting the estimation of LAI, and eventually the canopy interception. Therefore, it is imperative to acknowledge the discrepancy between the modelled and actual data (ZHANG & GOODCHILD 2002), and how such limitation influences the inaccuracy and uncertainty of the results.

This study adopted the calculation of canopy interception storage that is simplified and modelled in MIKE SHE. In this hydrologic model, the capacity of canopy interception must be filled before the throughfall and stemflow occur (DHI 2007), although, in reality, the rainfall can reach the ground and generate runoff before the canopy interception storage reaches its maximum capacity (DURANEL 2015). YANG et al. (2019) argued that canopy interception is affected by the rainfall intensity, as more rainfall is intercepted during low precipitation.

The presence of large trees has a significant influence on flood regulation, such as Kiara Payung (Filicium decipiens) and Suren (Toona sureni). Filicium decipiens is a tropical fern-like leaf tree native to Asia and Africa. Typically, high altitude areas up to 1000 m are home to the plant. There are plenty of these evergreen trees throughout the country. The leaves are big and complex with 12-16 leaflets per leaf. Kiara Payung is a slow-growing tree with a height that can reach 10 metres or more. Its canopy resembles a dome with dense foliage. With these characteristics, Filicium decipiens can provide a better effect for cooling down the surface temperature below the trees. On the other hand, Suren (Toona sureni) or Chinese Toon is a deciduous plant native to the eastern and southeastern parts of Asia (PENG et al. 2019). This tree is a part of the mahogany family and has an oval-spreading appearance. It can reach a height of 20 metres and a width of 10 metres. The tree can be pruned frequently to reduce its length and achieve a more compact, bush-like form. It can be utilized as a shade tree, focal point or planted along streets. Regarding the effect of cooling temperatures as well as rainwater interception, the Suren tree provides less effect than the Kiara Payung tree. Thus, multiple ecosystem services that a particular tree can provide (e. g., flood regulation, climate regulation, and cultural service) should be considered as an important element in designing and planning urban areas.

5 Conclusion

This study demonstrates how LAI and canopy storage of trees in an urban park can be estimated from point cloud data generated from both ALS and TLS, and by adopting the Kristensen and Jensen method which is commonly used in hydrologic modelling. It is estimated

that all trees in the case study area contribute to intercept more than half of precipitation during the day with the highest rainfall intensity in 2018. This research, however, assesses only one segment of the hydrologic processes (i. e., canopy interception) within one time step. Therefore, future studies should include other factors that influence the runoff-generating process (e. g., evapotranspiration, evaporation, soil infiltration, etc.) in the analysis. With the rapid development of point cloud modelling as a medium for landscape design, the methods presented in this paper can be adopted to estimate the potential canopy interception of the trees proposed in different landscape design and planning scenarios.

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