Jurnal
Teknologi

Full Paper

COMPARISON OF CANOPY COVER EFFECTS ON RAINFALL INTERCEPTION LOSS IN TROPICAL FOREST WITH HOMOGENOUS AND MIXED TREE SPECIES

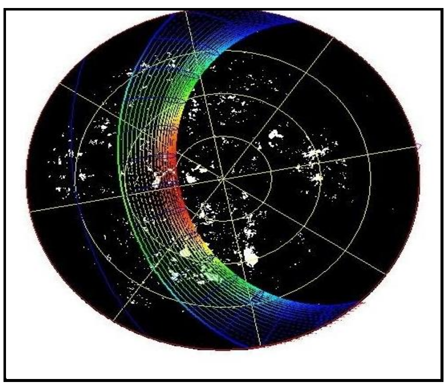
Azinoor Azida Abu Bakar[a*], Zulkiflee Abd Latif[b], Wei-Koon Lee[c]

[a]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA Cawangan Johor, Kampus Pasir Gudang, Bandar Seri Alam, 81750 Masai, Johor, Malaysia
[b]Faculty of Surveying Science & Geomatics, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Malaysia
[c]School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Malaysia

Article history
Received
16 September 2021
Received in revised form
15 February 2022
Accepted
15 November 2022
Published Online
23 February 2023

*Corresponding author
azinoor@uitm.edu.my

Graphical abstract



Abstract

This study was designed to determine the canopy cover, c of the tropical forest and explore its effects on the interception loss amount. The study area was a reserved forest Lagong Hill Forest Reserve, Kepong, Selangor, Malaysia, where two plots with an area of 400 m^2 (20 m x 20 m) each have been set up to collect the data. In order to determine the measured interception loss, rainfall, throughfall, and stemflow data have been measured on site. The tree with a diameter at breast height (dbh) of more than 10 cm was selected in collecting the stemflow data. Twenty-five (25) locations have been chosen for the digital hemispherical photographs to be taken. The forest standing of the study area has been visualised by Stand Visualization System (SVS) method, and WinSCanopy 2009a and RGBFisheye.exe application software has been used to obtain the canopy cover values. In this study, the correlation between canopy cover and interception loss were obtained for both plots. It is found that the Lagong Hill Forest Reserve varied has a compact canopy density with canopy cover up to 95%. This condition will affect the canopy interception loss value ranging from 24.83% up to 64.72%. The canopy cover and interception loss correlation denote that the interception loss amount reduces whilst the canopy cover increases.

Keywords: Canopy cover, canopy interception, hemispherical photographs, rainfall, tropical forest

Abstrak

Kajian ini bertujuan untuk mengetahui penutupan kanopi di hutan tropika dan juga untuk mengetahui kesannya terhadap jumlah pintasan curahan. Kawasan kajian adalah hutan simpan Hutan Simpan Bukit Lagong, Kepong, Selangor, Malaysia, di mana dua plot dengan luas 400 m^2 (20 m x 20 m) telah dibentuk untuk pengumpulkan data. Untuk menentukan jumlah pintasan curahan, jumlah hujan, curahan terus dan lelehan batang telah diukur di lokasi. Pokok dengan diameter pada ketinggian paras dada (dbh) lebih dari 10 cm dipilih untuk mengumpulkan data lelehan batang. Dua puluh lima (25) lokasi telah dipilih untuk diambil gambar hemisfera digital. Kawasan hutan di kawasan kajian telah divisualisasikan dengan kaedah Stand Visualization System (SVS) dan perisian aplikasi WinSCanopy 2009a dan RGBFisheye.exe telah digunakan untuk mendapatkan nilai penutupan kanopi. Dalam kajian ini, hubungan antara penutup kanopi dan lelehan batang diperoleh untuk kedua-dua plot kajian. Didapati bahawa Hutan Simpan Bukit Lagong yang bervariasi mempunyai kepadatan kanopi yang padat dengan penutup kanopi hingga 95%. Keadaan ini akan mempengaruhi nilai kehilangan pintasan curahan kanopi antara 24.83% hingga 64.72%. Korelasi penutupan kanopi dan pintasan curahan menunjukkan bahawa jumlah kehilangan pemintasan berkurang apabila penutupan kanopi meningkat.

Kata kunci: Penutupan kanopi, pintasan kanopi, gambar hemisfera, hujan, hutan tropika

1.0 INTRODUCTION

The canopy cover is referred to as the crown cover, or canopy coverage, and can be expressed as the fraction of the forest area covered by the vertical projection of the tree crowns [1-3]. Canopy cover also can be presumed as the actual value of the over storey cover [4]. In the hydrological cycle, the canopy cover affects the rainfall-runoff hydrology in many different ways as it retains rainwater during rainfall before it reaches the ground. In the forest conditions, interception loss shows a significant function as the shrubbery cover, which affects the water balance calculation applied in estimating the volume of water storage in water catchment. In the water budget concept, interception loss is a key parameter in the hydrological cycle that affect the site and the catchment water balance [5]. This phenomenon can accumulate up to 15 to 50% of the rainfall volume in natural forests [6-7]. Due to that, it is a significant part of the hydrological process for the water budget. One can adopt different types of canopy interception value, such as from the on-site measurement or from the model computation, which can also interplay with each other [8].

Gross rainfall (rain above canopies) is separated into three categories by tree canopies: throughfall, stemflow, and interception. A fraction of the rainfall is intercepted and temporarily held by the canopies before evaporates. The term for this phenomenon is called interception loss. The canopy architecture and meteorological conditions both have impact on canopy interception loss [9]. Tree canopy quantification is essential for interception study. The canopy cover in natural forests and replanted plantations show distinct characteristics due to the different conditions which influence the growth of the tree canopy [10]. The factors that affected the growth of the canopy of the tree include nutrition, water obtained, infection, pest infestations, and stress. Other purposes of measuring the canopy cover is to determine the efficiency of the fertilisation process, the effectiveness of irrigation, and thinning techniques in agriculture.

The forests canopies are vital in watershed areas for various reasons, including regulating the water cycle and promote groundwater recharge. Study on forest canopy cover has emerged as an essential component of forest inventories. For starters, canopy cover has been presented as a versatile ecological marker that can distinguish between animal and plant habitats and assess forest light conditions and floor microclimate. It can also evaluate functional variables such as leaf area index (LAI), which measures the photosynthetic leaf area per unit ground area [11-12].

Modern remote sensing implementations provides automatic canopy data reading over large aerial extent and can be applied to separate tree canopy test area [13] for the assessment of canopy cover [14] or as a first step in differentiating the indicators produced from the forest floor and the forest canopy. When utilising experimental or physical-based vegetation reflectance models to estimate LAI, canopy cover is an essential supplementary variable [15-16]. Field-based canopy cover measurements are required to validate remotely sensed canopy cover estimations and the development of novel remote sensing techniques. The United Nations Food and Agricultural Organization (FAO) defines a forest as a land no less than 0.5 ha with canopy cover of over 10% and tree height of at least five metres [17].

Numerous studies have presented the correlation between forest elements to interception. Crockford and Richardson, 2000 [9] and Azinoor and Khairudin, 2017 [18] show the effects of forest type on the interception loss values. Staelens *et al.,* 2006 [19] derived the relationship between canopy cover and throughfall process, Manfroi *et al.,* 2004 [20] studied the effects of diameter at breast height (dbh) with stemflow and Dietz *et al.,* 2006 [21] investigated on the effects of tree height and leaf area index to throughfall. Crockford and Richardson, 2000 [9] stated that larger crown size and canopy gaps would generate enormous interception loss. Admittedly, canopy gaps and crown size are significant parameters in determining the interception of a study area.

Other studies show that canopy cover is a crucial measure of the forest condition and it is used in studies of climate change reduction, disease observation, and forest management [22]. While the canopy cover affects the rainfall interception, it also is affected by the rainfall temporal resolution [23]. Unfortunately, there is still a lack of study concentrating on the significances of forest stand canopy cover to the canopy interception, especially for tropical forest. Therefore, this paper aimed to present the correlation between canopy cover and interception loss in the tropical forest.

2.0 METHODOLOGY

2.1 Study Area

The study was conducted in a primary lowland mixed dipterocarp forest reserved forest in Lagong Hill Forest Reserve, Selangor (3° 15' N and 101° 37' E) and is located in the Peninsular of Malaysia. The reserve covers an area of 485 hectares where about 78% is planted forest. This forest is partitioned into 53 fields with over 60 different categories and species of plants [24]. The location of Lagong Hill is shown in Figure 1.

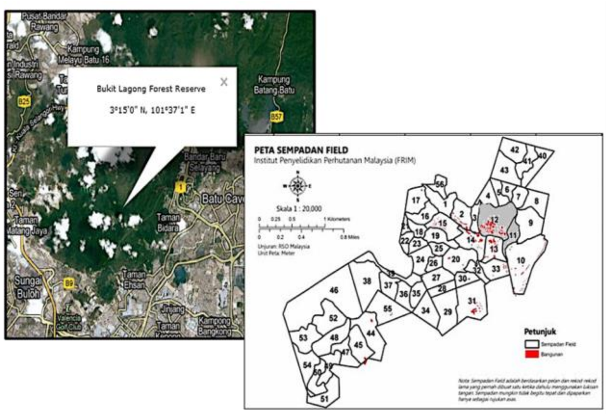


Figure 1 The location of the study area

2.2 Canopy Characteristics

Two plots, namely Plot 11 and Plot 12, have been set - up in this study area to collect data on throughfall, stemflow, and canopy cover. The plots were marked with PVC pickets with 20 m x 20 m square size area. The plots have 400 m^2 each and have sub-grids of 5 m x 5 m interval length. In both plots, trees with a diameter at breast height (dbh) more than 10 cm were identified, marked and numbered. In Plot 11, there are 21 trees; meanwhile, in Plot 12, there are 20 trees. Trees in Plot 11 are mainly Kulim species, whereas Plot 12 is a mixture of *Kledan*, *Mempisang*, *Simpoh* and *Keruing* species. For canopy characteristics, the height of the canopy was measured. The average height of the canopy for Plot 11 and Plot 12 is up to 17 m and 29.5 m, respectively [25]. The forest standing in the study area has been visualised in 3D view using Visualization System (SVS) based on the selected trees over the study plots.

2.3 Measurement of Rainfall, Throughfall and Stemflow

The daily rainfall data was collected for 12 months from April 2012 until April 2013 except August 2012 due to technical problems. The gross rainfall was measured using non-recording rainfall gauge where the gauge was placed 30 m from the study plot. The existing rainfall gauge was operated by Malaysia Meteorological Department (MMD). The rainfall data were collected on daily basis and were compared with the rainfall data determined from Taman Tun Teja rainfall station (ID: 3315039; 3° 18' N, 101° 35' E) operated by the Department of Drainage and Irrigation Malaysia.

Throughfall is measured using 25 regular bucket collectors with a 225 mm diameter orifice measuring 200 mm deep. The bucket collectors were placed at each intersection plot grid below the canopy cover with 5 meters interval. The data is averaged out on a daily basis. Because the canopy area of the forest is dense, the volume of throughfall was divided with the receiving area of the collector to obtain throughfall value in depth (mm) [26].

The stemflow was collected using a halved rubber collar, which wrapped around each selected tree stem spirally. The selected trees were determined based on the diameter of the breast height within the plot area. There are 15 trees for each plot that has been selected in setting up the stemflow collar. The trees are accessible and have a dbh of more than 10 cm. Water drains from the stem via the spiral rubber collar into a collecting tank installed at the end of the collar. In this study, the rubber collar was made of PVC hose and was fitted around the tree stem using nails. Silicone glue was applied to seal the gap between the stem and the collar. Initially, 4 number of 5.5 litres capacity collecting tanks were used and emptied daily. However, these were changed to 10 litres tanks on 14 April 2012, and later replaced with 25 litres tanks on 22 May 2012 due to overflow. The volume of stemflow collected was converted to depth (mm) using the method by Bo *et al*., 1989 [27].

2.4 Measurement of Canopy Cover

The WinsCanopy 2009a and the application software RGBFisheye.exe has been employed to obtain the value of the canopy cover. Photograph of the canopy cover was taken at 25 intersection grid points for each plot, and the images were analysed using RGBFisheye.exe software. The software calculates the dispersed transmittance in % PPFD, i.e. the canopy cover's forest photosynthetic photon flux compactness. The PPFD is calculated automatically from the digital hemispheric pictures taken from the site, and it required the light setting established from the luminance of the zenith of the sky [28]. Figure 2 (a) and (b) show the method used to perform SVS at both plots.

(a)

(b)

Figure 2 The method used to perform SVS

2.5 Interception Loss as a Function of Canopy Cover

Study by other researchers found that the process of rainfall interception usually is dependent on the rainfall characteristics (e.g., rainfall amount, intensity, duration, drop size, and the number of raindrops). Most studies focus on one or more variables of the same group [29-30]. Other factors that may affect the interception process are micrometeorological conditions, forest features such as tree species, the canopy structure (e.g., leaf area index (LAI), stem surface area, and crown gap fraction), and the antecedent weather [31]. Rainfall characteristics and forest canopy architecture have been recognised as the leading factors controlling the forest canopy interception of rainfall [9][32].

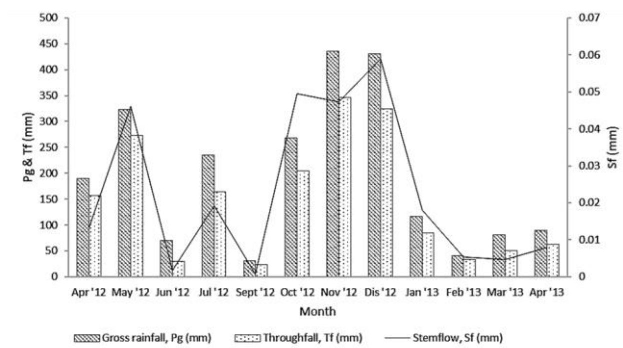
3.0 RESULTS AND DISCUSSION

3.1 Rainfall, Throughfall and Stemflow Measurement

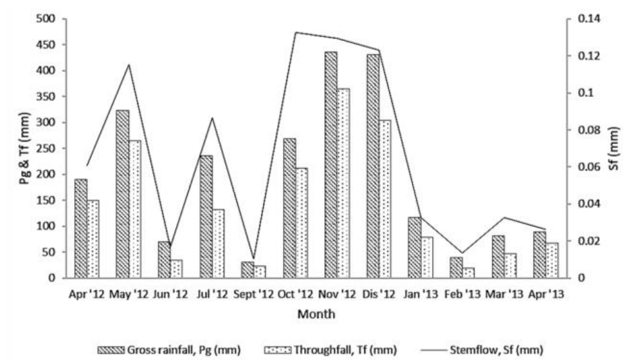
Measurements of gross rainfall, throughfall and stemflow were carried out manually. The data were collected from 11 April 2012 until 24 April 2013, which is over a period of twelve-month except for missing data during the month of August 2012 due to some technical problem. The rainfall was measured using standard manual rain gauges installed in an open area adjacent to both plots. There are 94 rainfall events recorded during the 12 months. The minimum gross rainfall recorded is 1.4 mm on 28 September, and 12 October 2012, whereas the maximum rainfall events recorded was 109.7 mm on 18 April 2012.

Figure 3 (a) and (b) show the monthly gross rainfall, throughfall and stemflow during the study period for Plot 11 and Plot 12, respectively. The wettest seasons were recorded from October until December 2012, with 2095.84mm within the study periods. The highest monthly rainfall recorded was 405 mm in November 2012, whereas the lowest was 21 mm in February 2013.

For the throughfall data, the percentage over gross rainfall for Plot 11 is 78.71% and for Plot 12 is 80.96%, respectively. The throughfall volume constitutes a significant part of gross rainfall since the rainfall drips from the canopy cover over the canopy's storage. The throughfall measurement tank placed at the intersection of a grid point in the plot might receive direct rainfall which is not in contact with the canopy. For stemflow data, it gives the value of 0.013% and 0.034% of gross rainfall for Plot 11 and Plot 12, respectively. The difference between gross rainfall and net rainfall (throughfall and stemflow) is measured as interception loss.



(a)

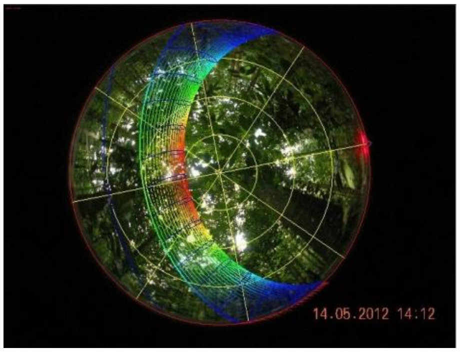


(b)

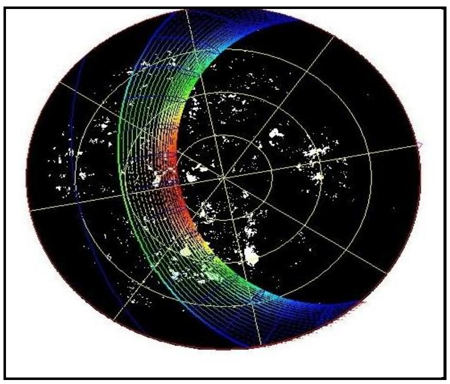
Figure 3 Monthly rainfall, throughfall and stemflow for (a) Plot 11 and (b) Plot 12

3.2 Canopy Cover Assessment

The data of canopy cover was determined using WinSCanopy 2009a and the application RGBFisheye.exe software. The sample images captured by the Fisheye lens are shown in Figure 4 (a) and (b). The 25 images were analysed, and the canopy cover percentage was obtained, as shown in Figure 5.



(a)



(b)

Figure 4 Image captured using a Fisheye lens (a) in standard view and (b) after analysis

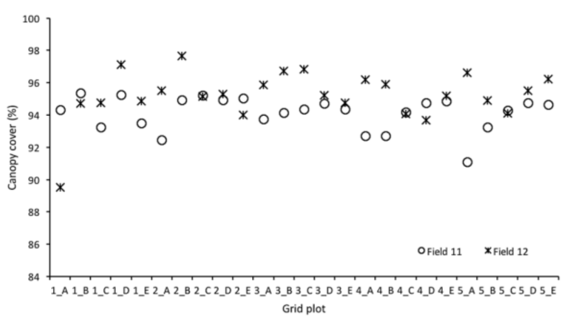


Figure 5 Canopy cover (%) at Plot 11 and Plot 12

From the results, the assessment of canopy cover obtained at Plot 11 varied from 88.5% to 97.5% and for Plot 12, from 92.7% to 97.2%. Table 1 shows the max, min, mean and standard deviation of the canopy cover for Plot 11 and Plot 12. Evidently, Plot 12 gives a higher canopy cover value than canopy cover measured at Plot 11. Furthermore, the variability of canopy cover in Plot 11 is wider. Plot 12 exhibits narrower range of canopy cover attributed to the diverse mix of tree species. The findings of the canopy cover obtained from this study show that Lagong Hill Forest Reserve is categorised as a dense forest, as agreed with the finding stated by Ibrahim *et al.*, 2008 [24].

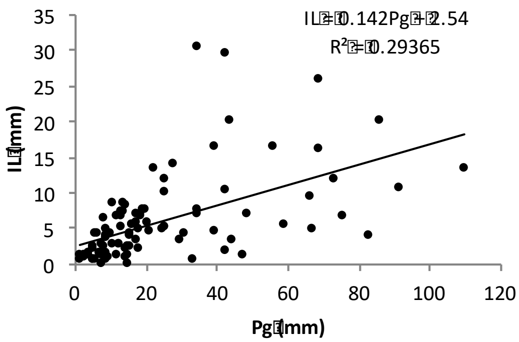
Table 1 Descriptive statistics (max, min, mean ± standard deviation) of canopy cover for study plots

Grid Point	Canopy cover (%)	
	Plot 11	**Plot 12**
1_A	94.31	89.53
1_B	95.35	94.73
1_C	93.23	94.74
1_D	95.27	97.12
1_E	93.5	94.85
2_A	92.46	95.49
2_B	94.92	97.65
2_C	95.22	95.16
2_D	94.94	95.28
2_E	95.03	93.99
3_A	93.73	95.86
3_B	94.14	96.73
3_C	94.36	96.83
3_D	94.71	95.23
3_E	94.36	94.76
4_A	92.71	96.19
4_B	92.72	95.89
4_C	94.19	94.07
4_D	94.76	93.69
4_E	94.86	95.17
5_A	91.08	96.61
5_B	93.26	94.89
5_C	94.29	94.11
5_D	94.74	95.49
5_E	94.65	96.21
Mean	94.11	95.21
Max	95.35	97.65
Min	91.08	89.53
Std dev	1.048	1.57

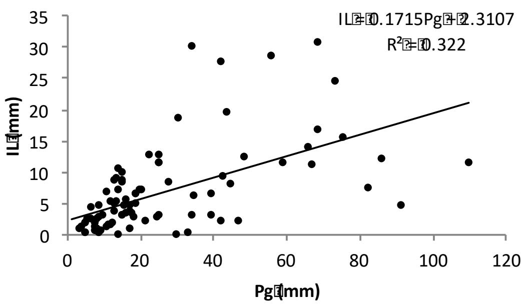
The leaf area is an essential factor influencing rainfall partitioning [33]. Study by Nielsen *et al.*, 2012 [34] found a strong relationship between LAI and canopy cover. One of the characteristics of vegetation that affects the interception process is canopy cover density. A canopy on the ground is very effective in holding and reducing rainfall, thereby suppressing the kinetic energy of the fall of raindrops that will reach the ground. Vegetation canopy closure significantly affects the hydrological cycle, especially on the canopy interception process. Closer canopy cover will reduce the speed of falling raindrops when reaching the surface of the forest floor [8].

3.3 Canopy Interception Loss

Canopy interception of rainfall is a dynamic process; thus, the interception ratio is not a constant value [30]. The interception loss is measured by computing the excess of the rainfall with throughfall and stemflow. The rainfall, throughfall and stemflow data were collected for 12 months from April 2013 to April 2013 except for August 2012 due to some technical issue.



(a)



(b)

Figure 6 Correlation of interception loss with gross rainfall at (a) Plot 11 and (b) Plot 12

From the site interception loss measurements, the interception loss for Plot 11 is 13.5% and for Plot 12 is 10.8% of the gross rainfall for the 12-month duration. Figure 6 shows the correlation of interception with gross rainfall loss along with the study duration. It shows that at Plot 11, the correlation can be written as IL = 0.142Pg + 2.54; meanwhile, the correlation of interception loss with gross rainfall can be written as IL = 0.1715Pg + 2.3107. Based on the correlation derived, it is shown that Plot 11 with single tree species has higher initial interception but lower interception rate at higher gross rainfall compared to Plot 12 with mixed tree species.

In this study, the value of the interception loss varies from 10% up to 16% and is in good agreement with findings reported by Carlyle-Moses and Price, 1999 [35], Asdak *et al.*, 1998 [36] and Nik *et al.*, 1979 [37]. Asdak *et al.*, 1998 [36] conducted the study area at Wanariset Sangai at the upstream sections of the Sungai Mentaya at Central Kalimantan; meanwhile, Nik *et al.*, 1979 [37] conducted the study at Air Hitam Forest Reserve in Puchong, Selangor. The site condition is almost similar to Lagong Hill Forest Reserve, Kepong, Selangor. In addition, both forests are classified as tropical rainforests. It is also noted that the error range is smaller for Plot 11 due to the homogeneity of the tree's species. Plot 12 shows larger error range which may be attributed to slightly different interception characteristics of the different tree species, and hence the combined effect. Table 2 shows the average, range and standard deviation of the species, crown diameter, dbh and height of the tree at study plots.

Table 2 Average, range and standard deviation of the species, crown diameter, dbh and height of the tree at study plots

Plot 11			
Species	**Crown Dia. (m)**	**DBH (cm)**	**Height (m)**
Kulim	5.05	12.2	10.9
Kulim	5.91	23.7	15.0
Kulim	6.98	38.6	15.2
Kulim	4.99	26.9	14.0
Kulim	3.89	31.3	15.2
Kulim	4.54	17.0	14.6
Kulim	8.60	35.1	15.2
Kulim	5.72	46.6	17.1
Kulim	2.22	11.8	11.1
Kulim	2.82	11.5	6.4
Kulim	4.77	12.1	17.5
Medang Kemangi	9.95	63.1	15.3
Kulim	3.70	18.8	16.5
Kulim	3.92	22.7	16.3
Kulim	2.93	10.0	13.1
Kulim	3.71	13.8	9.6
Kulim	1.42	11.7	3.9
Kulim	7.11	18.4	15.4
Kulim	5.68	39.1	15.9
Kulim	2.98	14.8	12.5
Average	4.84	24.0	13.5
Range	8.53	53.1	13.6
Std dev	2.0837	13.9584	3.4801

Plot 12			
Species	**Crown Dia. (m)**	**DBH (cm)**	**Height (m)**
Kledan	12.86	32.9	19.3
Pulai	2.11	18.8	19.8
Mempisang	12.17	19.2	17.0
Sena	5.37	13.1	12.4
Kledan	4.30	41.4	27.3
Perah	6.08	17.6	19.3
Perah	7.58	16.9	12.6
Kledan	4.89	36.9	29.2
Kulim	5.71	12.4	14.3
Keruing	6.72	44.0	16.5
Keruing	8.11	44.1	23.4
Mempisang	5.79	10.6	12.8
Kulim	6.17	25.3	14.8
Simpoh	4.32	32.1	29.8
Simpoh	4.65	41.4	23.8
Kulim	4.43	12.3	10.8
Kulim	3.95	20.3	17.5
Simpoh	4.56	38.4	29.8
Perah	6.01	17.2	14.5
Simpoh Gajah	3.90	24.7	29.5
Average	5.98	26.0	19.7
Range	10.75	33.5	19.0
Std dev	2.5515	11.4523	6.3718

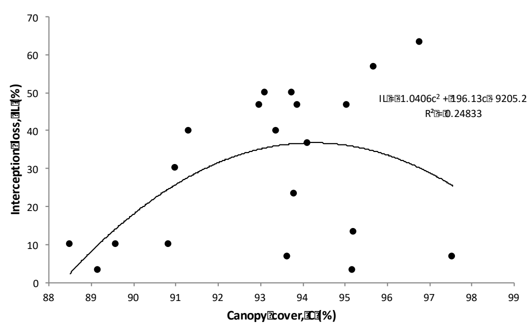
The rainfall data were also classified into wet and dry seasons. The polynomial power 2 relationship is applied to show the best fit of the correlation between the gross rainfall and the interception loss for both seasons (Table 3). The R^2-values of the correlation shows evident improvement when the data is split into wet and dry seasons for both Plot 11 and Plot 12. Furthermore, the correlation is higher for dry season compared to wet season, consistent with the findings by Chen and Li (2016) [38]. The higher interception loss during dry season can be attributed to the higher water-carrying capacity of the canopy. Meanwhile, during wet season, the canopy is more likely to be saturated, and thus the interception loss is less sensitive to the amount of rainfall.

Table 3 Polynomial regression between interception loss and gross rainfall during dry and wet season for Plot 11 and Plot 12

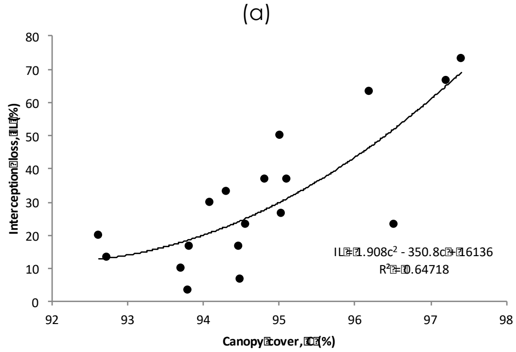
Season	**Plot 11**	**R^2**
Wet	$IL = -0.0018Pg^2 + 0.2871Pg + 0.8995$	0.3165
Dry	$IL = 0.001Pg^2 + 0.2918Pg + 0.2749$	0.429
Season	**Plot 12**	**R^2**
Wet	$IL = -0.0031Pg^2 + 0.4413PG – 1.2353$	0.4344
Dry	$IL = -0.0048Pg^2 + 0.5956Pg – 1.7322$	0.5616

3.4 Canopy Cover's Impact on Interception Loss

The effects of canopy cover on the interception loss of the study area have been determined by the point correlation analysis. 25 points of canopy cover for Plot 11 and Plot 12 were associated with interception loss using polynomial regression. The correlation has been done separately to figure out the difference between these 2 plots.



(a)



(b)

Figure 7 The correlation of interception loss (%) to canopy cover (%) at (a) Plot 11 (b) Plot 12

From the correlation analysis, the best relationship of canopy cover in Plot 11 to the interception loss is represented by $IL = -1.0406c^2 + 196.13c - 9205.2$ with R^2 value of 0.2483, whereas in Plot 12, the best relationship obtained by R^2 value of 0.6472 with the equation of $IL = 1.908c^2 – 350.8c + 16136$. For both equations, IL represents the interception loss in percentage and c represents the canopy cover of the plot in percentage unit. The findings show that the correlation between canopy cover and interception loss indicates that the interception loss decrease as the canopy cover increase.

The higher the canopy cover value means that the denser the forest, the higher the interception loss process will occur. Nevertheless, if the canopy is saturated, the interception value will be reduced [8]. From Figure 7 (a) and (b), it is interesting to note that the interception correlation with canopy cover exhibits concave behavior for Plot 11 but convex behavior for Plot 12. This suggests Plot 11 shows diminishing interception properties despite increased canopy cover whereas Plot 12 shows enhanced interception properties as canopy cover increases.

The difference in interception in the two forests may also be caused by factors such as the leaf area index (LAI), the age of the stand, the width of the canopy and the wind. Furthermore, trees with larger crown surface area tend to have more sizeable tree branches. These woody surface areas have water-holding capacity and take time to saturate. This factor will affect the amount of rainwater that can be temporarily detained by the vegetation canopy, which will then be evaporated back into the atmosphere. The opening of the forest has increased the percentage of rain under a canopy, which resulted in the value of interception of the canopy [8].

4.0 CONCLUSION

The fisheye lens was used to capture the hemispherical photography of forest canopy to develop canopy cover images at 25 intersection points at Plot 11 and Plot 12 of the study area. The images were analysed using WinSCanopy 2009a and RGBFisheye.exe software. Results show that Lagong Hill Reserve Forest's canopy cover ranges from 88.5% to 97.5% for Plot 11 and 89.5% to 97.6% for Plot 12, respectively. Hence, the average values of canopy cover obtained are 93.7% and 95.0% for Plot 11 and Plot 12. Plot 11 with single tree species has higher initial interception but the capacity at increased rainfall is lower. Furthermore, the increase of interception capacity with canopy cover exhibits concave behavior. On the other hand, Plot 12 with mixed tree species has lower initial interception but the capacity at increased rainfall is higher, and its interception capacity exhibits convex behavior with increased canopy cover. In brief, the correlation relationship resulting from the canopy cover and interception loss is positive and has a significant correlation.

Acknowledgement

The authors acknowledge the research grants provided by Universiti Teknologi MARA Cawangan Johor under Geran Penyelidikan Bestari (GBest) Sepadanan Phase 1/2020 (600-UiTMCJ (PJIA. 5/2).

References

[1] Avery, T. E. and Burkart, H. E. 1994. *Forest Measurements.* McGraw-Hill. 331.

[2] Crookston, N. L. and Stage, A. R. 1999. Percent Canopy Cover and Stand Structure Statistics from the Forest Vegetation Simulator. Gen. Tech. Rep. RMRS-GTR-24, Ogden, UT: U. S. Department Agriculture, Forest Service, Rocky Mountain Research Station. 11. DOI: https://doi.org/10.2737/RMRS-GTR-24

[3] Korhonen, L., Korhonen, K. T., Rautiainen, M., Stenberg, P. 2006. Estimation of Forest Canopy Cover: A Comparison of Field Measurement Techniques. *Silva Fenn*. 40(4): 577-588.

[4] Alessandro, P. and Vittorio, T. 2009. Forest Canopy Cover and Canopy Closure: Comparison of Assessment Techniques. *Eur J Forest Res*. 128: 265-272. Doi: 10.1007/s10342-009-0262-x.

[5] van Djik, A. I. J. M. and Brujinzeel, L. A. 2001. Modelling Rainfall Interception by Vegetation of Variable Density using an Adapted Model Analytical Model. Part 1. Model Description. *Journal of Hydrology*. 247(3-4): 230-238. https://doi.org/10.1016/S0022-1694(01)00392-4.

[6] Baiamonte, G. 2021. Simplified Interception/Evaporation Model. *Hydrology*. 8: 99. https://doi.org/10.3390/hydrology8030099.

[7] José, N. 2020. Modeling Rainfall Interception Loss Components of Forests. *Journal of Hydrology*. 584: 124449. https://doi.org/10.1016/j.jhydrol.2019.124449.

[8] Astuti, H. P. and Suryatmojo, H. 2019. Water in the Forest: Rain-vegetation Interaction to Estimate Canopy Interception in a Tropical Borneo Rainforest. *IOP Conf. Series: Earth and Environmental Science*. 361: 012035 Doi:10.1088/1755-1315/361/1/012035.

[9] Crockford, R. H. and Richardson, D. P. 2000. Partitioning of Rainfall into Throughfall, Stemflow and Interception Effect of Forest Type, Ground Cover and Climate. *Hydrological Processes*. 14: 2903-2920. https://doi.org/10.1002/1099-1085(200011/12)14:16/17<3C2903::AID-HYP126>3E3.0.CO;2-6.

[10] Rautiainen, M., Stenberg, P. and Nilson, T. 2005. Estimating Canopy Cover in Scots Pine Stands. *Silva Fennica*. 39: 137-142. Doi:10.14214/sf.402.

[11] Jennings, S. B., Brown, N. D. and Sheil, D. 1999. Assessing Forest Canopies and Understorey Illumination: Canopy Closure, Canopy Cover and Other Measures. *Forestry: An International Journal of Forest Research*. 72(1): 59-74. https://doi.org/10.1093/forestry/72.1.59.

[12] Lowman, M. D. & Rinker, H. B. (eds.). 2004. *Forest Canopies.* 2nd ed. Elsevier Academic Press. 517.

[13] Kalliovirta, J. and Tokola, T. 2005. Functions for Estimating Stem Diameter and Tree Age using Tree Height, Crown Width and Existing Stand Database Information. *Silva Fennic*. 39(2): 386. https://doi.org/10.14214/sf.386.

[14] Gemmell, F. 1999. Estimating Conifer Forest Cover with Thematic Mapper Data Using Reflectance Model Inversion and Two Spectral Vegetation Indices in a Site with Variable Background Characteristics. *Remote Sensing of Environment*. 69: 105-121. Doi: 10.1016/S0034-4257(99)00004-8.

[15] Knyazikhin, Y., Martonchik, J. V., Myneni, R. B., Diner, D. J. and Running, S. W. 1998. Synergistic Algorithm for Estimating Vegetation Canopy Leaf Area Index and Fraction of Absorbed Photosynthetically Active Radiation from MODIS and MISR Data. *Journal of Geophysical Research*. 103: 32257-32276. https://doi.org/10.1029/98JD02462.

[16] Kuusk, A. and Nilson, T. 2000. A Directional Multispectral Forest Reflectance Model. *Remote Sensing of Environment*. 72: 244-252. Doi:10.1016/S0034-4257(99)00111-X.

[17] FAO. 2000. On Definitions of Forest and Forest Change. Forest Resources Assessment Programme. Working Paper 33. FAO, Rome, Italy. 15.

[18] Azinoor Azida Abu Bakar and Muhammad Khairudin Khalil. 2017. Preliminary Study on Tropical Forest Canopy Interception. *Journal of Engineering and Applied Sciences.* 12(21): 5572-5577. Doi: 10.36478/jeasci.2017.5572.5577.

[19] Anna Kowalska, Andrzej Boczon, Robert Hildebrand, Zaneta Polkowska. 2016. Spatial Variability of Throughfall in a Stand of Scots Pine *(Pinus sylvestris L.)* with Deciduous Admixture as Influenced by Canopy Cover and Stem Distance. *Journal of Hydrology*. 538: 231-242. http://dx.doi.org/10.1016/j.jhydrol.2016.04.023.

[20] Manfroi, O. J., Koichiro, K., Nobuaki, T., Masakazu, S., Nakagawa, M., Nakashizuka, T., Chong, L. 2004. The Stemflow of Trees in a Bornean Lowland Tropical Forest. *Hydrological Process.* 18(13): 2455-2474. Doi: 10.1002/hyp.1474.

[21] Dietz, J., Holscher, D. and Leuschner, C. 2006. Rainfall Partitioning in Relation to Forest Structure in Differently Managed Montane Forest Stands in Central Sulawesi, Indonesia. *Forest Ecology Management*. 237(1-3): 170-178. https://doi.org/10.1016/j.foreco.2006.09.044.

[22] Jill M. Derwin, Valerie, A. Thomas, Randolph H. Wynne, John W. Coulston, Greg C. Liknes, Stacie Bender, Christine E., Blinn, Evan B. Brooks, Bonnie Ruefenacht, Robert Benton, Mark V. Finco, Kevin Megown. 2020. Estimating Tree Canopy Cover using Harmonic Regression Coefficients Derived from Multitemporal Landsat Data. *Int J Appl Earth Obs Geoinformation*. 86: 101985. https://doi.org/10.1016/j.jag.2019.101985.

[23] Azinoor-Azida, A. B. and Minjiao, L. 2015. Annual Canopy Interception at Artificial Lowland Tropical Forest. *Hydrol. Earth Syst. Sci. Discuss.* 12: 4879-4907. Doi:10.5194/hessd-12-4879-2015.

[24] Ibrahim, S., Parlan, I., Hamzah, K. A., Mahmood, N. N. Z., Harun, I., Yahya, A. Z., Omar, H., and Mohammad, A. 2008. *FRIM Tapak Warisan Semulajadi.* Gemilang Press Sdn. Bhd., Selangor.

[25] Azinoor, A. A. B., Aminuddin, B., Nurakmal, H., Zulkifli, Y. and Muhammad, K. K. 2012. Throughfall, Stemflow and Interception Loss of Artificial Tropical Forest. *IEEE Colloquium on Humanities. Sciences and Engineering Research*. 92-96. Doi: 10.1109/CHUSER.2012.6504289.

[26] Yusop, Z., Cham, S. Y., and Chong, J. H. 2003. Throughfall, Stemflow and Interception Loss of Old Rubber Trees. *Jurnal Kejuruteraan Awam.* 15(1): 24-33.

[27] Bo, M. W., Tae, H. K., and Kyong, H. K. 1989. Rainfall Interception Loss from Canopy in Forest Catchment. *IHP-UNESCO-FRIM Regional Seminar on Tropical Forest Hydrology*. Kuala Lumpur.

[28] Ishida, M. 2005. Manual of RGBFisheye.exe: An Application Software for Automatic Calculation of Diffuse Transmittance (%PPFD) with Hemispherical Photographs. Center of Educational Research in Field Science, Gifu Faculty of Applied Biological Science, Japan.

[29] Pérez-Suárez, M., Arredondo-Moreno, J. T., Huber-Sannwald, E., and Serna-Pérez, A. 2014. Forest Structure, Species Traits and Rain Characteristics Influences on Horizontal and Vertical Rainfall Partitioning in a Semiarid Pine–oak Forest from Central Mexico. *Ecohydrology*. 7: 532-543. Doi:10.1002/eco.1372.

[30] Sheng, H. and Cai, T. 2019. Influence of Rainfall on Canopy Interception in Mixed Broad-Leaved - Korean Pine Forest in Xiaoxing'an Mountains, Northeastern China. *Forests.* 10(3): 248. Doi:10.3390/f10030248.

[31] Livesley, S.J., Baudinette, B., Glover, D. 2014. Rainfall Interception and Stem Flow by Eucalypt Street Trees - The

Impacts of Canopy Density and Bark Type. *Urban Forestry & Urban Greening*. 13(1): 192-197. https://doi.org/10.1016/j.ufug.2013.09.001.

[32] Yan, W., Deng, X., Chen, X., Tian, D., Xiang, W. and Peng, Y. 2015. Long-term Variations of Rainfall Interception in Different Growth Stages of Chinese Fir Plantations. *Hydrol. Sci. J*. 60(12): 2178-2188. DOI:10.1080/02626667.2014.964243.

[33] Liu, H. J., Zhang, R. H., Zhang, L. W., Wang, X. M., Li, Y. and Huang, G. H. 2015. Stemflow of Water on Maise and Its Influencing Factors. *Agric. Water Manage.* 158: 35-41. Doi: 10.1016/j.agwat.2015.04.013.

[34] Nielsen, D., Miceli-Garcia, J. J. and Lyon, D. J. 2012. Canopy Cover and Leaf Area Index Relationships for Wheat, Triticale, and Corn. *Agronomy Journal*. 104(6): 1569-1573. https://doi.org/10.2134/agronj2012.0107n.

[35] Carlyle-Moses, D. E. and Price, A.G. 1999. An Evaluation of the Gash Interception Model in a Northern Hardwood Stand. *Journal of Hydrology*. 214: 103-110. https://doi.org/10.1016/S0022-1694(98)00274-1.

[36] Asdak, C., Paul G. J., and Paul, V. G. 1998. Modelling Rainfall Interception in Unlogged and Logged Forest Areas of Central Kalimantan, Indonesia. *Hydrology and Earth System Sciences.* 2: 211-220. https://doi.org/10.5194/hess-2-211-1998.

[37] Nik, M. M., Hamzah M. B. and Ahmad, S. 1979. Rainfall Interception, Throughfall and Stemflow in a Secondary Forest. *Pertanika.* 2: 152-154.

[38] Chen, Y. Y and Li, M. H. 2016. Quantifying Rainfall Interception Loss of a Subtropical Broadleaved Forest in Central Taiwan. *Water.* 8: 14. Doi:10.3390/w8010014, 1-19.