PAPER • **OPEN ACCESS**

The effect of rainfall interception loss by Palm-Oil tree towards flood discharge in Seunagan watershed of Nagan Raya district of Aceh Province

To cite this article: A Yulianur BC *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **523** 012041

IOP Conf. Series: Materials Science and Engineering **523** (2019) 012041 doi:10.1088/1757-899X/523/1/012041

The effect of rainfall interception loss by Palm-Oil tree towards flood discharge in Seunagan watershed of Nagan Raya district of Aceh Province

A Yulianur BC[1,*], Azmeri[1], Khairuddin[2]
[1]Lecturer, Faculty of Civil Engineering, Syiah Kuala University, Darussalam, Banda Aceh, Indonesia
[2]Officer, Water Resources Department of Aceh Province, Lueng Bata, Banda Aceh, Indonesia

E-mail: fian_7anur@yahoo.com

Abstract: Flood discharge comes from the surface run-off affected by factors such as evaporation, evapotranspiration, infiltration and interception. This research aims to predict the magnitude of interception demonstrated by a palm-oil tree and its effects toward flood discharge. This paper covers the calculations for rainfall interception loss by a palm-oil tree, designed areal rainfall, and designed flood discharge. During the calculations, the watershed is divided into two sub-watersheds. Rainfall data were obtained from Meulaboh, Beutong and Alue-Bilie station. Areal rainfall distribution obeys the pattern of Gumbel distribution. Areal rainfall of 100 years returns period for each sub-watershed are 230.81 mm and 197.59 mm before the inclusion of interception effects, while after interception effects are included the areal rainfalls are 152.94 mm and 189.09 mm. The calculated effective rainfall using the SCS (soil conservation service) method where the curve number (CN) before interception effects are 72.19 and 73.15 while 81.54 and 73.99 after the interception is accounted. Flood discharge is calculated using the method of unit hydrograph synthetic SCS. Calculation results show that designed flood discharge of 100 years return period before and after the effects of interception were 3,042.72 m3/s and 2,521.23 m3/s, respectively. It shows that rainfall interception loss by the palm-oil tree can reduce the flood discharge.

1. Introduction

Rainfall within a particular watershed will become runoff, and runoff is affected by factors such as interception. Hydrologist conducted numbers of researches [5],[6],[9],[13],[14] in modeling the interception of rain by various types of plants. Rao (1986) conducted a rain interception by cashew-plant at Kottamparamba India in 1983 and 1984. The percentage of rain that intercepted by this plant was 31%. Kaimuddin (1994 commenced a prediction modeling study of rain interception by Pines (*Pinus merkussi),* Dammar *(Agathis loranthifolia)* and Needlewood *(Schima wallichii)* in the educational forest of mount *Walat, Sukabumi, Indonesia.* He found that the rain interception demonstrated by Pines, Dammar, and Needlewood were 15.7%, 14.7% and 13.7%, respectively. Other than that, higher rainfall inflicting higher interception and older plants demonstrated higher interception.

*Corresponding author: fian_7anur@yahoo.com

IOP Conf. Series: Materials Science and Engineering **523** (2019) 012041 doi:10.1088/1757-899X/523/1/012041

This research aims to identify the rain interception contributed by the palm-oil tree. Simultaneously, accurately predicting the surface runoff of *Seunagan* watershed by perceiving those achieved interception by the palm-oil tree. The research was conducted on 10 years old palm-oil tree, rainfall were measured based on stemflow and throughfall. To determine the magnitude of interception, the amount of rainfall is deducted by the amount of stemflow and the amount of throughfall. The calculated interception value was then being input in designed flood discharge calculation for Seunagan watershed. Synthetic unit hydrograph soil conservation service (SCS) method was utilized to calculate the designed flood discharge where the effective rainfall as the surface runoff were influenced by land cover and soil type. Correspondingly, switching land cover into palm-oil tree contributes towards the magnitude of curve number.

2. Literature Review

2.1 Rain Interception

Rainfall interception is a process of rain falling on the surface of vegetation, detained for an immediate period, then being vaporized into atmosphere or absorbed by pertinent vegetation. Interception process occurs continuously during the rainfall and post-rainfall until the surface of the vegetation canopy dried out. During rainfall, some of the water never reach the ground, therefore it does not contribute in ground humidity, runoff water or groundwater. That water will return to the atmosphere as intercepted water by a canopy, litter, and lower plantation [1]. This is called rainfall interception loss.

Rainfall on the surface of vegetation canopy reaches the ground surface through two mechanisms, namely throughfall and stemflow. Throughfall is the portion of precipitation which immediately falls to the ground surface through the space between canopy/leaves or drips through leaves, stems and branches Stemflow is the rainfall which reaches the ground surface by flowing inside the plant stem.

2.2. The Measurement of Rainfall Interception

Measuring interception in canopy scale is performed by the volume balance approach. The measurement of rainfall interception in trees using volume balance approach is illustrated by Figure 1 as follows:

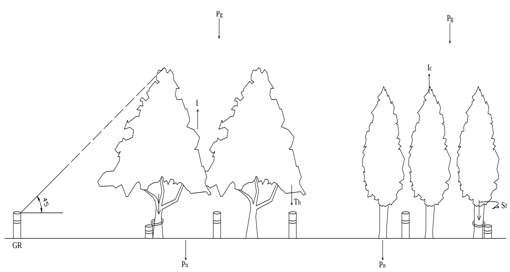

Figure 1. Measurement of rainfall interception in the plantation (Asdak, 2004)

According to the above Figure 1, an equation can be established to determine the magnitude of interception demonstrated by tree plantation during a particular plot of research. The equation is formalized as follow [1]:

$$I_c = P_g - (T_h + S_f) \quad (1)$$

Where I_c is canopy interception, P_g is the total rainfall (gross precipitation) (mm), T_h is throughfall (mm), and S_f is stemflow (mm).

2.3 Measurement of Rainfall

Rainfall measurement is performed to determine the amount of rainfall which not pertained by plants. Daily and weekly rainfall are initial components that are required to be determined using rainfall measurement gauge in an open field without any hindrance by any plants.

2.4 Measurement of Throughfall
The most integrated method in calculating throughfall is by using an apparatus called plastic-sheet gauge or by installing a plastic sheet beneath forest stands which collect water from throughfall as well as stem flow water. The arrangement of plastic is designed in such a way so that the water gathered from throughfall and stemflow are directed into gathering tank [1].

2.5 Measurement of Stemflow
Stemflow is obtained by installing zinc plates forming a circle covering the plants circumference so that the flow from branches and stem could be fully collected into gathering tank or recorded by tipping bucket gauge [1].

2.6 Thiessen Method.
Thiessen Method is one method to calculate the areal rain with the following formula [7],[15],[16].

$$P = \frac{A_1P_1 + A_2P_2 + A_3P_3 + ... + A_nP_n}{A_1 + A_2 + A_3 + ... + A_n} \quad (2)$$

where P is average areal rainfall, P_1, P_2, ...Pn are rain in station 1,2,.....n, while A_1, A_2, ...An are a representative area of station 1,2, 3....,n.

2.7 Estrem Value Distribution
Designed rainfall is calculated according to the type of data distribute matching. Among other distributions are as follows.

2.7.1 Log normal and log Pearson type III distribution. The equation of lognormal and log Pearson type III distribution are[15],[16]:

$$Log\ R_T = Log\ R + K_T S_d \quad (3)$$

Where R_T is designed rainfall for T years return period (mm), R is average rainfall (mm), K_T is frequency factor, S_d is standard deviation (mm). Frequency factor *(K_T)* for lognormal distribution is determined based on C_v and return period, while frequency factor *(K_T)* for log Pearson type III distribution is determined based on C_s and return period.
2.7.2 Gumbel Distribution. The estimation of rainfall by Gumbel distribution is as follows [15],[16]:

$$R_T = R + K_T S_d \quad (4)$$

$$K_T = \frac{Y_T - Y_n}{S_n} \quad (5)$$

$$Y_T = -Ln\left(-Ln\frac{T-1}{T}\right) \quad (6)$$

Where R_T is designed rainfall for T years return period (mm), R is average rainfall (mm), K_T is frequency factor, S_d is standard deviation (mm), T is the year of the return period, Yn is reduced mean Sn standard deviation, Y_T is reduced variate.

2.8 Alternating Block Method
Alternating Block Method (ABM) is one method to form a designed rainfall hyetograph [7]. ABM requires hourly rainfall intensity data concentrated at concentration time. The Mononobe formula is one of the formulas for calculating the hourly rainfall intensity, as follows [16].

$$I_t = \left(\frac{R_{24}}{24}\right)\left(\frac{24}{t_c}\right)^{2/3} \quad (7)$$

Where I_t is T years return period rainfall intensity (mm/hour), R_{24} is T years return period maximum daily rainfall (mm), t_c is the concentration-time that can be calculated by the Kirpich Formula, as follows[7].

$$t_c = 0.0195\left(\frac{L}{\sqrt{S}}\right)^{0,77} \tag{8}$$

Where t_c is concentration-time (minute), L is river length (m), and S is the river slope.

2.9 SCS Effective Rainfall

Effective rainfall or excess rainfall are parts of rain which become direct flow in the river. The soil conservation service (SCS) [7] has developed a method to calculate effective rainfall within heavy rain as expressed:

$$P_e = \frac{(P-0,2S)^2}{P+0,8S} \tag{9}$$

$$S = \frac{25400}{CN} - 254 \tag{10}$$

$$I_a = 0.2\,S \tag{11}$$

$$F_a = \frac{S(P-I_a)}{P-I_a+S} \tag{12}$$

Where P_e is the depth of effective rainfall (mm), P is rainfall depth (mm), S is the maximum water retention potential of the soil, which mainly cause by infiltration (mm), *CN Curve Number* is a function of watershed characteristic, I_a is initial abstraction, and Fa is continuing abstraction.

2.10 SCS Synthetic Unit Hydrograph.

The method of SCS synthetic unit hydrograph is a non-dimensional hydrograph where its ordinate describes the comparison between the discharge and the peak discharge while its abscissa describes the ratio of the interval between time and peak discharge time. Designed flood discharge is calculated based on designed rainfall while considering the watershed condition. Data Analysis forming unit hydrograph is performed by using the equation [7].

$$Q_n = \sum_{m=1}^{n\leq M} P_m U_{n-m+1} \tag{13}$$

Where Q_n is direct runoff discharge of the pulse of n, P_m is effective rainfall of the pulse of m; and U is unit hydrograph ordinate.

3. Research Methodology

This research is conducted in *Desa Jati Rejo Kec. Kuala Pesisir Kabupaten Nagan Raya.* The primary data used was the data collected from the research location consisting rainfall data which measured by a rain gauge, stemflow and throughfall, while secondary data are obtained from corresponding institutes/offices.

3.1 Rainfall Interception Research Method

The research is conducted towards ten years old palm-oil tree, the height of 7.50 m, canopy diameter of 11 m, and stem diameter of 85 cm. The research data analysis was conducted to determine the rain interception by a palm-oil tree which measured in the field. The conducted data analysis were rain interception analysis, rainfall data, throghfall data, stemflow data and the relationship between rainfall and stemflow. Eventually, rainfall measurement results, throughfall, and stemflow are utilized to calculate the magnitude of interception based on volume balance approach.

3.2 The correlation between rainfall and interception

The statistical approach will reveal the relationship between rainfall and interception which illustrated by the correlation graph of interception and rainfall where the regression equation will be obtained to show that relationship. The data of rainfall, after subtracted by the magnitude of interception will be the parameter in calculating the flood discharge at the watershed of *Seunagan Kabupaten Nagan Raya.*

3.3 Rainfall Analysis

The analysis of rainfall data in this research was established based on ten years of rainfall history from 2 rain gauge stations, namely Meulaboh and Beutong. From each rain, the station is calculated designed rainfall of 100-year return period based on suitable distribution. Determination of distribution types performed by Chi-Square test and Smirnov-Kolmogorov test. Then this designed rainfall is used to establish the areal designed rainfall by using the Thiessen Method. Furthermore, formed designed rainfall hyetograph by using ABM for rain that has not and has been reduced by the interception of rain by palm trees. After that for both formed effective designed rainfall hyetograph by using SCS method.

3.4 Analysis of flood peak discharge.

Synthetic unit hydrograph SCS method was utilized to calculate the discharge caused by rain that has not been and has been extracted by the value of rainfall interception loss. Based on the land cover map, Seunagan watershed is assumed to have varieties of land cover thus its flood surcharge should be calculated to obtain its peak surcharge value. Furthermore, mapping the terrain which has the potentials to turn into the palm-oil field based on the hillside slope map, land cover map, and soil type map at Seunagan watershed also based on the requirement of compatibility for the palm-oil tree. The value of interception will be included as one of the variables in the calculation of effective rainfall, the change of land cover also influences the potential retention values (S), where curve number (CN) will alter due to the change of land cover. Furthermore, the analysis will provide the peak surcharge of the flood after the effect of interception. Then a comparison is made between designed flood discharge hydrograph before and after rainfall interception by oil palm trees.

4. Result and Discussion

4.1 Designed Rainfall

In this research, due to its vast area, the watershed is divided into two sub-watershed. According to the calculation results, the watershed area is fathomed to have the area of 960.55 km^2. Designed rainfall is calculated to ascertain the magnitude of rainfall for return periods of 100 years. Meulaboh stations calculation for designed rainfall using Normal distribution result as 279.46 mm. While Meulaboh stations calculation for designed rainfall using Gumbel distribution result as 197.59 mm. The calculation of areal rainfall in Seunagan watershed using Thiessen Polygon method, for sub-watershed one extent of influence by Meulaboh station is 183.81 km^{2,} and Beutong station extent of influence is 269.23 km^2, while sub-watershed two only influenced by Beutong station by 507.51 km^2 with the overall area of the watershed of 960.55 km^2. Thus, designed rainfall for sub-watershed 1 is 230.81 mm and for sub-watershed two is 197.59 mm. After interception effect, designed rainfall for sub-watershed 1 is 152.94 mm and for sub-watershed two is 189.09 mm.

4.2 Determination of Curve Number (CN).

The types of land cover on Seunagan watershed is consist of primary dry forest, secondary dry forest, bushes, swamp grove, plantation, rubber plantation, rice fields, settlement, open field and water body. While the highest percentage of land cover is dominated by primary forest and secondary dry land, which are 39.02% and 24.06% respectively.The calculation presented composite CN value, where composite CN value is a merge of varies CN values multiply by the percentage of the type of soil towards varies type of land cover. Composite CN values for sub-watershed 1 is 72.19 and for sub-watershed 2 is 73.15. Any change in the composition of land cover types due to alteration of land function into palm-oil tree field also altered the value of CN, watershed outlet 1 has suitable palm-oil tree area of 290.78 km^2 with CN value of 81.54 while watershed outlet 2 has suitable palm-oil tree of only 43.04 km^2 with CN value of 73.99.

4.3 Designed Flood Discharge

The designed flood discharge calculation for the 100-year return period was carried out after first determining the effective rainfall hyetograph on conditions that have not been and there has been an interception of rain by the oil palm trees and also includes CN values before and after the oil palm trees exist. Then using the SCS hydrograph unit method obtained a designed flood hydrograph. Based on flood hydrograph before the influence of rain interception by oil palm trees, sub-watershed 1 have peak flood of 100-year return period is 1,484.80 m^3/sec, and for sub-watershed 2 is 1,557.91 m^3/sec. Thus, the magnitude of discharge passing the whole watershed outlet is 3,042.72 m^3/sec. After the effect of rain interception by oil palm trees, sub-watershed 1 has peak flood of 100-year return period is 1,030.82 m^3/sec, and for sub-watershed 2 is 1,490.41 m^3/sec. Therefore, the magnitude of surcharge passes the watershed outlet after the interception is 2,521.23 m^3/sec. Figure 2 and 3 shows a comparison of designed flood discharge hydrograph before and after rainfall interception by oil palm trees. This picture shows that conversion of land to oil palm plantations will reduce flood discharge due to the interception of rain by oil palm trees.

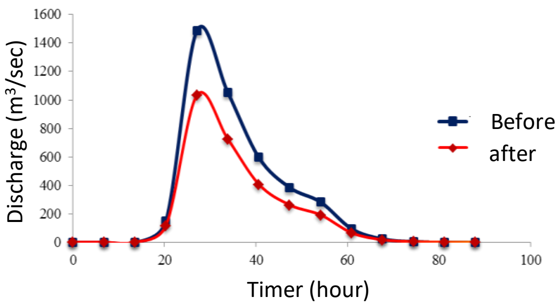

Figure 2. Flood Hydograph of Sub-watershed 1

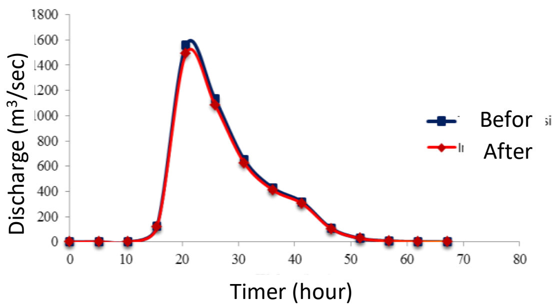

Figure 3. Flood Hydograph of Sub-watershed 2

5. Conclusion

Designed rainfall of 100-year return period for sub-watershed 1 is 230.81 mm and for sub-watershed two is 197.59 mm. After interception effect, designed rainfall for sub-watershed 1 is 152.94 mm and for sub-watershed two is 189.09 mm. Composite CN values for sub-watershed 1 is 72.19 and for sub-watershed two is 73.15. Any change in the composition of land cover types due to alteration of land function into palm-oil tree field also altered the value of CN, watershed outlet 1 has suitable palm-oil tree area of 290.78 km^2 with CN value of 81.54 while watershed outlet 2 has suitable palm-oil tree of only 43.04 km^2 with CN value of 73.99. Before the influence of rain interception by oil palm trees, sub-watershed 1 has peak flood of 100-year return period is 1,484.80 m^3/sec, for sub-watershed 2 is 1,557.91 m^3/sec, and the whole watershed outlet is 3,042.72 m^3/sec. After the effect of rain interception by oil palm trees, sub-watershed 1 has peak flood of 100-year return period is 1,030.82 m^3/sec, for sub-watershed 2 is 1,490.41 m^3/sec, and the watershed outlet after the interception is 2,521.23 m^3/sec. The conversion of land to oil palm plantations will reduce flood discharge due to the interception of rain by oil palm trees.

6. Reference

[1] Asdak, C 2004, *Hidrologi dan Pengelolaan Daerah Aliran Sungai* (Gajah Mada University Press), Yogyakarta.
[2] Balai Pengelolaan Daerah Aliran Sungai 2014, *Peta Tutupan Lahan DAS Krueng Seunagan Kabupaten Nagan Raya Tahun 2012*, (BP DAS Banda Aceh).

[3] Badan Meteorologi dan Klimatologi 2009, *Data Curah Hujan Stasiun BMKG Bandara Cut Nyak Dhien Kabupaten Nagan Raya tahun 2000 sampai 2009*, Aceh.
[4] Badan Investasi dan Promosi Aceh, 2014, *Detail Profil Proyek (Detail Plan of Investment) Komoditi Kelapa Sawit di Nagan Raya.*
[5] Bruijnzeel, LA 1990, *Hydrology of Moist Tropical Forests and Effects of Conversion: a State of Knowledge Review*. Humid Tropics Programme, (IHP-UNESCO, Paris, and Vrije Universiteit, Amsterdam).
[6] Cameron, JL 2007, *Influence of Crown Traits and Leaf Arrangement on Rainfall Interception, Throughfall, and Stemflow in Five Tropical Tree Species* (The University of Winnipeg).
[7] Chow, et. al, 1988, *Applied Hydrology* (McGrow-Hill Company) Singapore
[8] Dinas Perkebunan dan Kehutanan 2014, *Data Luas Perkebunan Kelapa Sawit di Kabupaten Nagan Raya* (Dinas Perkebunan dan Kehutanan Kabupaten Nagan Raya).
[9] Kaimuddin 1994. '*Kajian Model Pendugaan Hujan pada Tegakan Pinus merkusii, agathis loranthifolia dan Schima wallichii di Hutan Pendidikan Gunung Walat Sukabumi'*, Tesis, (Program Pasca Sarjana ITB) Bogor.
[10] Mangoensoekarjo, S dan Semangun, H 2005, *Manajemen Agribisnis Kelapa Sawit* (Gajah Mada University Press), Yogyakarta.
[11] Pahan, I 2013, *Kelapa Sawit Manajemen Agribisnis dari Hulu hingga Hilir* (Penebar Swadaya), Jakarta.
[12] Pangudijatno, G dan Purba, P 1987, 'Kesesuaian Lahan dan Keterkaitannya dengan Pembangunan Perkebunan Kelapa Sawit', *Prosiding Lokal Industri Kelapa Sawit*, Vol. 1, Medan 24 – 25 November 1987
[13] Pelawi, SF 2009, 'Intersepsi pada Berbagai Kelas Umur Tegakan Kelapa Sawit *(Elaeis Guineensis*)', Skripsi, (Fakultas Pertanian Universitas Sumatera Utara), Medan.
[14] Rao, AS 1986, *'Interception Losses of Rainfall from Cashew Trees', Journal of Hydrologi*.
[15] Soemarto, CD *1987. Hidrologi Teknik (*Usaha Nasional) Surabaya.
[16] Triatmodjo, B 2009, *Hidrologi Terapan* (Beta Offset) Yogyakarta.