ISSN 0024-9521
IJG Vol. 43, No. 2, December 2011 (97 - 110)

THE ROLE OF VEGETATION COVER AND CATCHMENT CHARACTERISTICS ON BASEFLOW IN BALI ISLAND

Saparis Soedarjanto
saparis68@yahoo.com
Unda Anyar Watershed Management Centre, the Ministry of Forestry

J. Sartohadi
panyidiksiti@yahoo.com
Faculty of Geography,Universitas Gadjah Mada

M.P. Hadi
mphadi@ugm.ac.id
Faculty of Geography,Universitas Gadjah Mada

P. Danoedoro
projo.danoedoro@geo.ugm.ac.id
Faculty of Geography,Universitas Gadjah Mada

ABSTRACT

Studies of the role of combined vegetation cover and catchment characteristics on base flow condition are required to address the controversy of correlation between vegetation and hydrological properties. Objectives of the research were: 1) to assess the hydrological role of vegetation on baseflow condition; and 2) to study the influence of vegetation cover in relation to catchment characteristics on the baseflow. Field survey, digital filter method, remote sensing technique, and statistical analysis were used to derive and assess the correlation among variables. Results of the research were: 1) a negative significant correlation between vegetation cover and baseflow recession coefficient, despite the fact that it is not a single factor and related to various catchment characteristics; 2) vegetation cover is not a single factor in determining the baseflow characteristics, since it also involves drainage density and infiltration rate.

Keywords: *vegetation cover, baseflow, statistical analysis*

ABSTRAK

Studi tentang peran tutupan vegetasi gabungan dan karakteristik DAS pada kondisi aliran dasar diperlukan untuk memahami kontroversi mengenai korelasi antara vegetasi dan sifat hidrologis. Tujuan dari penelitian ini adalah: 1) untuk menilai peran hidrologis vegetasi pada kondisi aliran dasar; dan 2) untuk mempelajari pengaruh tutupan vegetasi yang dikaitkan dengan karakteristik DAS pada aliran dasar. Survei lapangan, metode filter digital, teknik penginderaan jauh, dan analisis statistik digunakan untuk mendapatkan dan menilai korelasi antara variabel - variabel. Hasil penelitian ini adalah: 1) korelasi negatif yang signifikan antara tutupan vegetasi dan koefisien resesi aliran dasar, namun bukanlah faktor tunggal dan sejalan dengan hubungannya dengan karakteristik DAS; 2) tutupan vegetasi bukan merupakan faktor tunggal dalam menentukan karakteristik aliran dasar, tetapi juga melibatkan kerapatan drainase dan laju infiltrasi.

Kata Kunci : *tutupan kanopi, aliran dasar, analisis statistik*

INTRODUCTION

Several studies stated that forest is the major agent in reducing groundwater storage through evapotranspiration mechanism *Zadroga*, [1976]. [*Seyhan*, 1977; *Fetter*, 1980; *Chow*, 1988; *Knapp*, 2002; *Schipkan et al*. 2005; *Seiler* and *Gat*, 2007; *Dou et al*. 2008; *Cao et al*. 2009]. Inland precipitation transforms into evapotranspiration, and surface/subsurface run-off is. Groundwater and soil moisture consumed by plants are about 50% of the continental water cycle. *Seiler* and *Gat*, 2007 report that in humid tropical and temperate climates, 57% of green water is evapotranspirated through forests. Controversially, several researches indicate that forest generates the best possibility in improving soil infiltration capacity [*Lee*, 1980; *Ilstedt et al*. 2007; *Bruijnzeel*, 2009]. Forest trees produce a lot of mulch that increase organic matters on forest floor. The organic matters made the stable soil structures that provide higher macro pores. In the end, the infiltration capacity of forest soil is much higher than that of non forest land and leads to the improvement of groundwater storage.

Water deficit of 18.8 billion m^3 will happen in Java and Bali Islands in the year 2020. It is increased from the year 2003 with only 13.1 billion m^3. Java and Bali Islands are inhabited by 60% of Indonesian population. In 1986, the population of Java and Bali Island had water provision index of about 1.750 m^3/capita/year. That water provision status was categorized as critical situation based on World Water Resources Institute [*Weert*, 1994]. Some effort was applied to overcome the water crisis based on re-evaluating the contribution of vegetation cover on baseflow. According to *Seyhan*, [1977] run-off variation is affected by the relationship between climate and watershed characteristics that can be grouped into two categories: 1) ground factors (topography, soil, geology, and geomorphology), and 2) vegetation and land cover.

Proportional assessment of vegetation role should consider all the watershed characteristics that include topography, soil, geology, and geomorphology [*Seyhan*, 1977; *Seyhan* and *Keet*, 1981; *Sri-Harto*, 1991; *Reddy et al*. 2004).

There are two objectives to address in this research: 1) to assess the hydrological role of vegetation on baseflow condition; and 2) to study the influence of vegetation cover in relation to catchment characteristics on the baseflow.

Tropical monsoon area and quarter volcanic material of Bali Island absolutely control the correlation among various catchment characteristics. The situation above is the focus of this research.

Researches of the inter-correlation among run-off, forest cover, water loss and evapotranspiration have been done by *Zadroga* [1976], *Bruijnzeel*, [1990] and *Chow*, [1988]. *Bruijnzeel*, [2004] revealed there were no well documented cases that reforestation and soil conservation lead to increase the baseflow. The controversy of forest hydrologic role indicates that our knowledge about the dynamic actions of the vegetative cover on hydrologic and petrologic environment is very limited [*Bruijnzeel*, 1990].

Water consumed by vegetation is one of the important aspects to be addressed in assessing the forest hydrologic role. In fact, hydrology modelling tends to neglect or to simplify the role of vegetation in hydrologic cycle. The research of *Bonell* and *Bruijnzeel*, [2005] resulted confusing conclusion regarding the role of forest in water reduction. On one side, canopy transpiration and interception were playing double mechanisms of water reduction and of rainfall conservation by forest ecosystem. On the other side, it was concluded that forest conserves water of about 42% of hydro-electric production value in downstream area.

Furthermore, *Weert* [1994] reported that run-off coefficient of tropical rain forest is 0,03; that means forest is able to conserve rainfall of about 97% and the rest (3%) is an overland flow. Many facts showed significant relationships between vegetation and direct run-off, although the forest is not a single factor. Forest ability in controlling surface run-off indicates that forest contributes in gaining sub surface water.

The occurrence of vegetation has influenced all run-off components including direct run-off, interflow and baseflow. Groundwater is drained into channel as baseflow, and the baseflow becomes the major component of river stream during dry season. The role of vegetation cover in increasing infiltration and evapotranspiration is the important factor considered in the study of the relationship between vegetation cover and groundwater storage. In the end, baseflow analysis may be applied to assess the relationship between groundwater characteristics and vegetation cover.

THE METHODS

The research was carried out in two steps: field data collection and laboratory data analysis. The field data were collected from 30 watersheds in Bali Island as shown in Fig. 1 Canopy model is applied in this research to assess vegetation cover, instead of plant mechanism and stomata control [*Lee*, 1980]. Normatively, plant mechanism and stomata control approaches are appropriate for identifying conifer and eucalyptus species. From hydrological point of view, both species have specific hydrology properties regarding to their capacity in transpiration process [*Newson*, 1997]. However, these two species are not present in research area.

The watersheds were based on the occurrence of hydrometric instruments. The field data collection has also been done to derive infiltration rate on 21 land systems. The laboratory analysis covered digital filter for baseflow separation from total run-off. The digital image was proposed for canopy density evaluation. The statistical data analysis was applied to assess the correlation among variables.

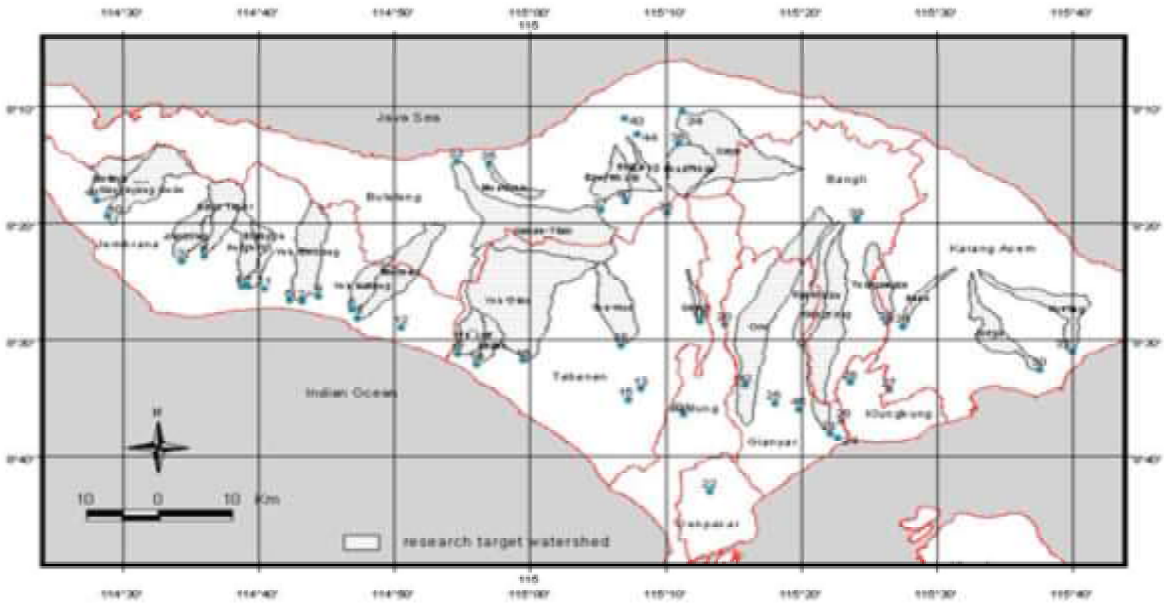

Figure 1. Map of research target

Baseflow separation and Baseflow recession coefficient

Base flow separation techniques used the time-series record of stream flow to derive the baseflow. The common separation methods were graphical which tend to focus on determining the points of baseflow line that intersects the rising and falling limb of the baseflow response. Graphical methods had limitation of quite subjective and leading to inconsistencies. Base flow separation from the entire hydrograph through digital filter method had suppressed the inconsistency and subjectivity. Two digital filter methods, issued by Lyne Hollick and Chapman [*Nathan* and *McMahon*, 1990], were applied in this research. Lyne Hollick equation for baseflow separation is presented in equation (1).

$$b_t = \alpha q_{t-1} + \frac{(1-\alpha)}{2}(Q_t - Q_{t-1}) \text{ ....(1)}$$

In equation (1), Q_t is the stream flow at time step t (day), while q_t and b_t are the corresponding run-off and baseflow components, α is the filter parameter associated with the catchments. Chapman pointed out that the Lyne-Hollick algorithm incorrectly provides a constant stream flow Q or baseflow b respectively when direct run-off has ceased and therefore, he developed the new algorithm in equation (2).

$$b_t = \frac{3\alpha - 1}{3-\alpha} b_{t-1} + \frac{1-\alpha}{3-\alpha}(Q_t + Q_{t-1}) \text{ .... (2)}$$

When the quick run-off component has ceased, the filter parameter α becomes the hydrological recession constant K in equation (3), which is commonly applied to describe baseflow recession during dry season periods.

$$Q_t = Q_0 K^t \text{ .... (3)}$$

Both equation (1) and equation (2) will be evaluated in this this research, and the better one will be applied to separate baseflow from total runoff.

Annual Discharge Publication issued by Bali-Penida Water Resources Service became the source of data.

Vegetation Cover Assessment

Vegetation cover density is a very important indicator in the forest hydrological research. Leaf Area Index (*LAI*) is the key variable in relation to plant biomass production. Accurate estimation of *LAI* is required for the prediction of microclimate and various biophysical processes within and below vegetation. *LAI* represents a vegetation cover density in the above land surface. The traditional, direct and destructive method of measuring *LAI* is time-consuming. Modern gap fraction technique may assess *LAI* fast and easily. *LAI* application has problem with vegetations of low stratum. Alternatively, remote sensing technique can become the efficient and effective ways to identify *LAI*.

NDVI (Normalized Difference Vegetation Index) is a widely used spectral reflectance index. *NDVI* provides good estimation of *LAI* and it was applied to estimate *LAI* indirectly [*Nagler et al*. 2004; *Fan*, 2008]. Landsat 7 ETM+ in path-row 117-066 and 116-066 with spatial resolution 30 m was applied to derive the *NDVI*. Correlation between *LAI* and *NDVI* was computed using simple regression analysis. Indirect non contact *LAI* measurement by semi hemispherical photograph of vegetation cover was promoted to be more effective and efficient of labours. The ENVI 4.5 software was applied to derive the *NDVI* value and to analyze semi hemispherical photo to determine the *LAI* value.

Morphometry calculation

Several researches done by hydrologists showed that morphometry was the key variable in assessing land and water relationship. In this research, there were 4 morphometry variables used to identify geomorphology having contributions toward base flow condition, such as: Length of Watershed (*LW*), Slope of

Watershed (*Sb*), Drainage Density (*Dd*) and Circularity Ratio (*Rc*).

The 1:25.000 topographic maps were becoming the source of data and Arc View GIS Software was applied to calculate those variables.

Infiltration

Infiltration Rate (*IR*) data was collected by direct measurement, using a double ring infiltrometer. Direct Measurement was conducted in the specified land system at such watershed. Infiltration rate at watershed scale was derived by using proportional computation method. All of the research variables are presented in Table 1.

Table 1. List of variables

No.	Variable	Symbol	Unit
1	Baseflow recession coefficient*	Brc	--
2	Canopy density index**	CDI	--
3	Length of watershed**	Lw	Kilometer (km)
4	Slope of watershed**	Sb	--
5	Drainage density**	Dd	Km/ Km^2
6	Circularity ratio**	Rc	Km
7	Infiltration rate**	IR	mm/hour

RESULT AND DISCUSSION

Baseflow separation technique

The result of the calculation using equation (1) and equation (2) are presented in Figure 2. Based on the graphical comparison of both methods and clarified by rainfall graphs in Figure 1, it can be concluded that equation (1) was giving better results. The major component of stream hydrograph during the dry season consists of baseflow, instead of a direct run-off. The diagrams, derived from the application of equation (1) method showed that there was no direct run-off in the dry season (compared to rainfall diagram).

The application of equation (2) was providing different results. There was a significance failure in equation (2) regarding the presence of direct run-off in the dry season. According to *Wilson* [1970], stream flow in the dry season is composed mainly by baseflow. In this season, there is no rainfall contribution and the river flow is contributed by groundwater discharge [*Schulz*, 1976; *Eckhardt*, 2005; *de Vries*, 1975]. They stated that baseflow is usually associated with water discharged from ground water storage. Considering the theoretical assessment and several hydrologist opinions, it is a reasonable consideration for this research to choose the equation (1) in separating the hydrograph to derive base flow component.

Canopy Density

Estimation of *LAI* as a representation of vegetation cover had been conducted to address the relevancy of vegetation cover in the hydrological studies. Proportion of light transmission calculation by semi hemispherical photograph method is presented in Figure 3 and Table 2. The relationships between Canopy Density Index (*CDI*) and *NDVI* in equation (4) and (5) can be done by considering Table 2.

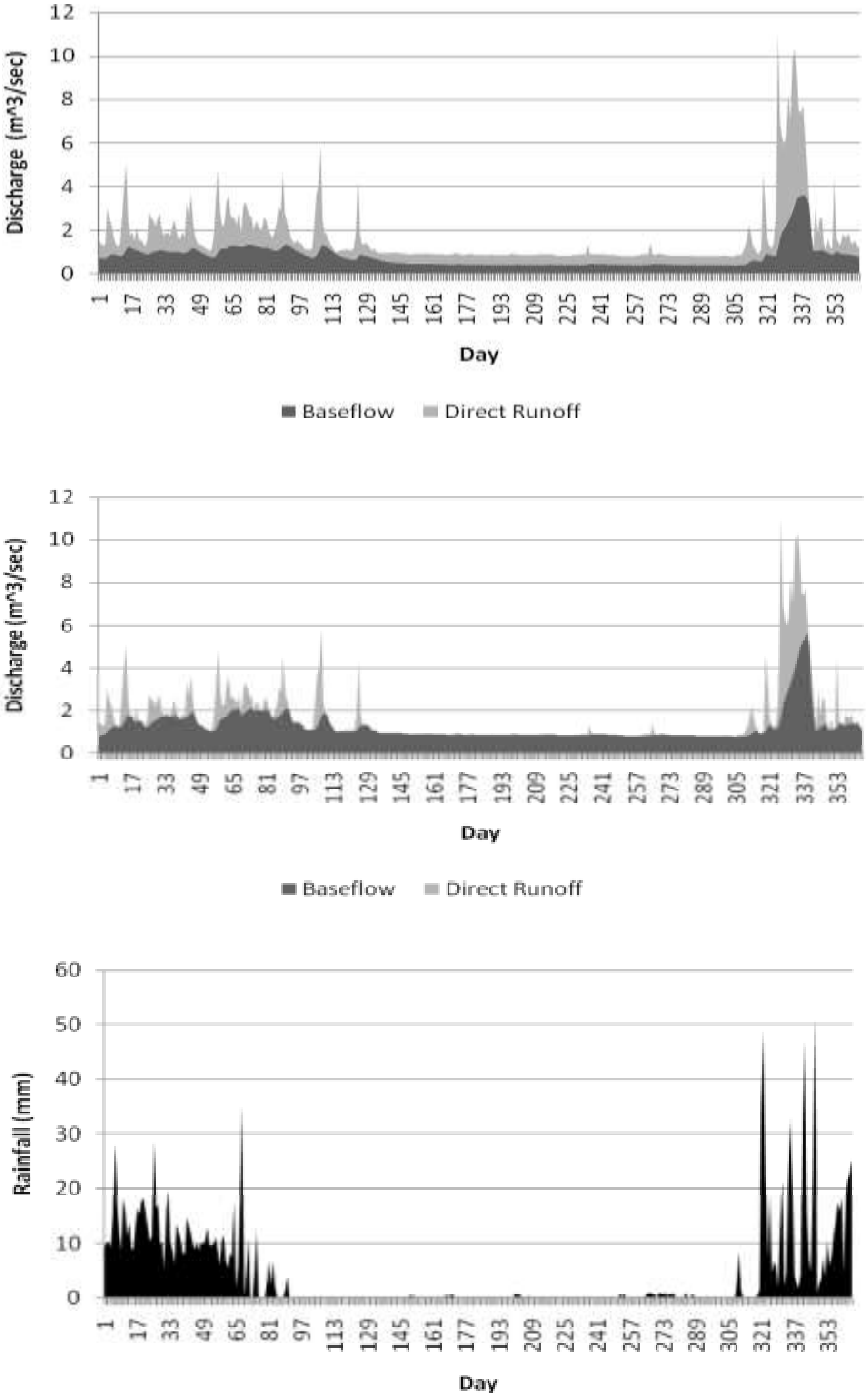

Figure 2. Hydrograph component of Jogading watershed (Bali Island) derived by equation (1) (upper), equation (2) (middle), and rainfall diagram (lower). All of the graphs present the data in the year 2003.

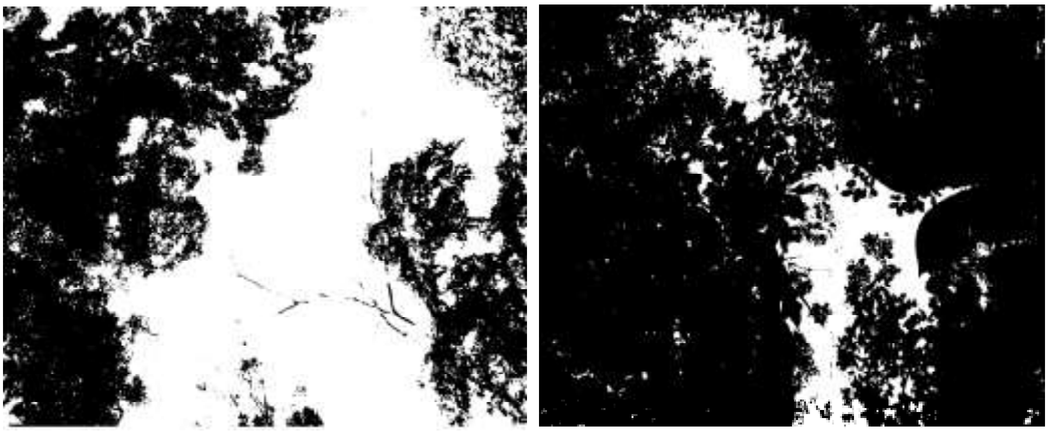

Figure 3. Vegetation density assessment using semi hemispherical photograph method in the forest area at Medewi watershed (left, VD = 0.53) and Balian watershed (right, VD = 0.85)

Table 2. Canopy density index (CDI) at various locations with specified NDVI value

No	Symbol	CDI	NDVI	Watershed	No	Symbol	CDI	NDVI	Watershed
1	BHt1	0.86	0.38	Balian	23	MHt3	0.93	0.36	Sanghyang Gede
2	BHt2	0.86	0.42	Balian	24	MHt4	0.77	0.29	Yeh Satang
3	BHt3	0.83	0.33	Balian	25	MHt5	0.67	0.31	Yeh Satang
4	BHt4	0.92	0.55	Yeh Otan	26	MHt6	0.73	0.30	Yeh Satang
5	BHt5	0.78	0.31	Yeh Otan	27	MHt7	0.20	0.33	Yeh Embang
6	Bsmp1	0.93	0.50	Nyuling	28	MHt8	0.34	0.35	Yeh Embang
7	Bsmp2	0.90	0.40	Nyuling	29	MHt9	0.60	0.34	Pergung
8	KtHt1	0.86	0.31	Daya Timur	30	MHt10	0.67	0.32	Pergung
9	KtHt2	0.58	0.29	Daya Timur	31	MHt11	0.78	0.36	Pergung
10	KtHt3	0.88	0.30	Daya Timur	32	MHt12	0.53	0.37	Medewi
11	KtHt4	0.93	0.56	Jogading	33	MHt13	0.77	0.41	Medewi
12	KtHt5	0.94	0.49	Jogading	34	MKb_1	0.87	0.42	Melaya
13	KtHt6	0.90	0.51	Jogading	35	MKb_2	0.90	0.41	Melaya
14	KtHt7	0.78	0.36	Ayung	36	MKb_3	0.89	0.47	Melaya
15	KtHt8	0.93	0.39	Ayung	37	MKb_4	0.96	0.48	Yeh Hoo
16	KtHt9	0.88	0.37	Ayung	38	MKb_5	0.96	0.44	Yeh Hoo
17	KtHt10	0.92	0.37	Janga	39	MKb_6	0.93	0.52	Yeh Leh
18	KtHt11	0.92	0.49	Janga	40	MKb_7	0.94	0.54	Yeh Leh
19	KtHt12	0.74	0.31	Buhu	41	MKb_8	0.84	0.52	Sanghyang Gede
20	KtHt13	0.62	0.38	Buhu	42	MKb_9	0.98	0.57	Sanghyang Gede
21	MHt1	0.88	0.43	Bilukpoh	43	MKb_10	0.99	0.59	Sanghyang Gede
22	MHt2	0.81	0.35	Bilukpoh					

1. Linier regression:
with correlation coefficient (r) = 0.56 and determinant coefficient (R^2) = 0.3136;
$NDVI = 0.2946CDI + 0.168$…………..…(4)

2.Exponential regression:
$NDVI = 0.2234e^{0.7122KT}$..........................(5)
with correlation coefficient (r) = 0.56 and determinant coefficient (R^2) = 0.3168.

The results of the correlation test using equation (4) and (5) and Figure 5 do not coincide with the research result of Fan [2008] on correlation between *LAI* and *NDVI* in Mongolia. Fan research's showed that *NDVI* can be applied to estimate *LAI* with correlation coefficient (r) equals to 0.7 and determinant coefficient (R^2) equals to 0.62. Nevertheless, it is still acceptable regarding that the value was higher than the threshold value (0.5) as stated by *Gordon* [1992].

Carreiras et al. research [2006] in Oak evergreen forest, Portugal proves that *NDVI* can be used for identifying canopy density with correlation coefficient (r) = 0.85 and determinant coefficient (R^2) = 0.72.

Effectiveness and accuracy of *NDVI* in assessing canopy density has also been promoted by *Martinuzzi et al*. [2008] based on their research conducted at dry tropical forest in the Caribbean Islands of Mona, Puerto Rico. He concluded that the *NDVI* is a practical tool for identifying vegetation types in areas with a great variety of plant communities and complex relief. *NDVI* is also possible to be applied to other dry forest habitats of the Caribbean Islands. *NDVI* is useful for identifying the distribution of forests, woodlands, and shrub land, providing a natural representation of vegetation patterns on the island.

As a result, sixteen land-cover types were mapped over 5,500 ha area, with a kappa coefficient of accuracy equals to 79%. Correlation of Vegetation Cover and catchment characteristics toward Base flow Characteristics.

The values of all variables to be addressed in this research are presented in Table 3. Simple regression analysis had been applied to assess the inter-correlation among variables. The Correlation matrix of these variables is presented in Table 4.

1. Linier regression:
with correlation coefficient (r) = 0.56 and determinant coefficient (R^2) = 0.3136;

$$NDVI = 0.2946CDI + 0.168 \quad \text{.............(4)}$$

2. Exponential regression:

$$NDVI = 0.2234e^{0.7122KT} \quad \text{..........................(5)}$$

with correlation coefficient (r) = 0.56 and determinant coefficient (R^2) = 0.3168.

The results of the correlation test using equation (4) and (5) and Figure 5 do not coincide with the research result of Fan [2008] on correlation between *LAI* and *NDVI* in Mongolia. Fan research's showed that *NDVI* can be applied to estimate *LAI* with correlation coefficient (r) equals to 0.7 and determinant coefficient (R^2) equals to 0.62. Nevertheless, it is still acceptable regarding that the value was higher than the threshold value (0.5) as stated by *Gordon* [1992].

Carreiras et al. research [2006] in Oak evergreen forest, Portugal proves that *NDVI* can be used for identifying canopy density with correlation coefficient (r) = 0.85 and determinant coefficient (R^2) = 0.72.

Table 3. Canopy Data recapitulation of all variables

No	Watershed	Area (km^2)	BCr	Lw (km)	Dd (Km/km^2)	Sb	Rc (km)	IR mm/hour	CDI
1	Medewi	45.45	0.94	17.57	4.13	0.50	9.60	5.32	0.58
2	Yeh Embang	42.49	0.97	15.26	2.84	0.29	13.43	4.75	0.65
3	Jogading	22.08	0.94	9.80	3.26	0.47	11.56	5.28	0.48
4	Yeh Satang	17.76	0.92	10.14	4.11	0.60	8.41	5.28	0.69
5	Bilukpoh	15.04	0.94	8.87	3.35	0.40	7.58	4.63	0.69
6	Pergung	20.82	0.92	11.55	3.92	0.46	9.62	7.02	0.65
7	Daya Timur	30.37	0.90	13.76	4.85	0.63	9.61	3.60	0.65
8	Sangiang Gede	48.27	0.97	13.12	2.50	0.25	14.90	3.24	0.52
9	Sungi	4.66	0.97	8.01	2.82	0.11	4.17	3.93	0.41

10	Yeh Otan	144.87	0.91	16.34	3.73	0.34	13.31	4.22	0.69
11	Yeh Leh	17.40	0.93	7.23	4.22	0.40	11.66	5.49	0.69
12	Yeh Hoo	37.17	0.99	12.59	2.63	0.28	16.09	6.81	0.52
13	Balian	12.10	0.98	6.69	2.53	0.34	7.91	3.44	0.48
14	Sangsang	71.62	0.96	15.03	2.29	0.18	13.55	5.23	0.52
15	Telagawaja	24.14	0.99	11.98	2.53	0.20	11.10	12.83	0.58
16	Janga	29.21	0.98	14.12	2.90	0.33	8.92	15.91	0.48
17	Buhu	7.39	0.92	6.79	4.03	0.35	4.97	3.98	0.52
18	Nyuling	33.17	0.99	8.57	2.46	0.26	9.50	9.48	0.48
19	Sabah Titab	130.46	0.93	15.75	2.58	0.37	12.94	3.13	0.55
20	Daya	78.21	0.96	16.49	3.10	0.43	13.81	7.46	0.52
21	Mendaum	6.84	0.99	5.08	2.28	0.35	4.50	8.27	0.38
22	Penarukan	31.99	0.97	7.98	3.79	0.31	17.57	7.76	0.52
23	Melaya	24.50	0.95	8.49	1.94	0.21	13.07	4.38	0.65
24	Oos	102.49	0.97	16.15	2.41	0.17	17.66	5.42	0.52
25	Banyumala	20.17	0.99	8.01	2.16	0.32	11.66	7.37	0.35
26	Buleleng	12.80	0.91	9.83	4.31	0.43	7.13	4.99	0.72
27	Pakerisan	32.00	0.92	18.68	4.84	0.21	9.63	4.28	0.58
28	Ayung	153.00	0.92	21.93	2.69	0.35	18.05	3.55	0.72
29	Badung	6.73	0.98	6.38	1.74	0.04	5.94	6.80	0.45
30	Petanu	58.41	0.94	18.67	2.63	0.19	11.96	4.94	0.48

Effectiveness and accuracy of *NDVI* in assessing canopy density has also been promoted by *Martinuzzi et al*. [2008] based on their research conducted at dry tropical forest in the Caribbean Islands of Mona, Puerto Rico. He concluded that the *NDVI* is a practical tool for identifying vegetation types in areas with a great variety of plant communities and complex relief.

Correlation of Vegetation Cover and catchment characteristics toward Base flow Characteristics. The values of all variables to be addressed in this research are presented in the Table 3.

Representation of vegetation patterns on the island. As a result, sixteen land-cover types were mapped over 5,500 ha area, with a kappa coefficient of accuracy equal to 79%.

NDVI is also possible to be applied to other dry forest habitats of the Caribbean Islands. *NDVI* is useful for identifying the distribution of forests, woodlands, and shrub land, providing a natural.

Simple regression analysis had been applied to assess the inter-correlation among variables. The Correlation matrix of these variables is presented in Table 4.

Table 4. Correlation matrix of assessed variables

	BCr	CDI	Lw	Dd	Sb	Rc	IR
BCr	1.000						
CDI	-0.711	1.000					
Lw	-0.330	0.319	1.000				
Dd	-0.743	0.539	0.135	1.000			
Sb	-0.554	0.443	0.033	0.645	1.000		
Rc	0.225	0.058	0.320	-0.320	-0.149	1.000	
IR	0.533	-0.293	-0.134	-0.206	-0.115	-0.078	1.000

Note: BCr is dependent variable 0.5 is threshold value in determining significant level of correlation among both variables [*Gordon et al*. 1992].

Several explanations can be addressed based on the matrix in Table 4, as follows:

1. There was a negative significant correlation between baseflow recession coefficient and canopy density index. The correlation coefficient value was equal to -0.71. This assessment showed that a canopy density affected groundwater absorption. Increment of canopy density was leading to a reduction of baseflow quantity. These results were in line with several hydrologists's researches [*Smith* and *Scott*, 1992; *Dou et al*. 2008; *Cao et al*. 2009; *Seiler* and *Gat*, 2007; *Kaimowits*, 2004]. According to *Bruijnzeel* [2009], 'scientific' perceptions tend to overemphasize high water use of trees.

This result absolutely disputes several opinions which was promoting the positive significance correlation between density of vegetative cover and baseflow quantity as stated by *Liu* [2004], *Dou et al*. [2008], *Huang* and *Zhang* [2004] and *Dou et al*. [2008].

2. The direct influence of vegetation in improving baseflow has not been clearly defined yet. Some hydrologists argue that the indirect role of vegetation is in line with the mulch produced by trees, which is subsequently increasing the organic matter of soil and improving the infiltration capacity [*Seyhan*, 1975; *Lee*, 1980; *Weert*, 1984; *Bharati et al*. 2002; *Davie*, 2002].

Improvement of soil infiltration capacity is indicated as driving forces of the baseflow quantity increment. According to *Seyhan* [1977], vegetative cover encourages the development of infiltration through overland flow reduction, and leads to a higher opportunity for water transmission to the sub surface zone.

3. The connection between infiltration and base flow condition had been verified in this research. Correlation matrix in Table 4 showed that there was a positive significant correlation between infiltration rate and baseflow recession coefficient (correlation coefficient value is equal to 0.53). The result had proved that soil infiltration was an agent of baseflow development [*Ilsted et al*. 2007; *Yue* and *Hashino*, 2005]. According to *Baskent* and *Keles* [2008], vegetation controls the quantity and quality of water infiltration to the soil, and as a consequence, affects the water supply to groundwater storage and soil moisture. The higher organic matter in the forest floor is leading to the higher infiltration rate in forest land than in non-forest land [*Lee*, 1980; *Weert*, 1984; *Purwanto*, 1999; *Anwar*, 2001; *Bharati et al*. 2002; *Davie*, 2002]. Assessment of soil water retention as an impact of soil infiltration capacity is an important watershed hydrology analysis, due to the potency of overland flow and the supply to groundwater storage [*Kosugi*, 1997].

According to *Seyhan* [1977], vegetative cover is not the single factor in influencing stream flow. It is affected by various factors including rainfall, geomorphology, and soil properties. Correlation matrix in Table 4 showed that there were two significant correlations between two optometry variables and baseflow recession coefficient.

The *Dd* and the *Sb* were two weak correlations between *Lw* and *Rc* to *Brc*. According to *Seyhan* and *Keet* [1981], there is a connection between hydromorphometry and run-off.

Groundwater storage is a source of base flow, so that there are some hydromorphometry variables that indicate a weak correlation with the baseflow variable, as shown by the weak correlation between *Lw* and *Rc* and *Brc*.

The hydrologic role of *Sb* was in line with the potency of drainage event. Sb is the main causative factor in influencing soil water retention [*Reddy et al*. 2004]. Based on several researches that have been conducted by hydrologists, *Dd* is a significant hydromorphometry variable in influencing streamflow and water transmission to the lower part of the land surface [*Reddy et al*. 2004; *Seyhan* and *Keet*, 1981; *Soewarno*, 1984; *Zavoianu*, 1985; *Talkurputra*, 1979]. In principle, the *Dd* is a representation of dissection intensity, as a function of the rainfall intensity, geological material, and physiographic response. The *Dd* incremental leads to a higher opportunity of water drainage through the channel. The situation affects on the reduction of water infiltration to the lower part of soil horizon, and will decline the baseflow potency. Considering the mechanism of water movement in the earth, *Ward* [1975] reveals that water movement on the land surface influences water supply to the groundwater system. The role of morphometry in base flow analysis is very important and it cannot be neglected.

The role of morphometry in influencing Available Water holding Capacity (*AWC*) of watershed is evidence in Reddy's research [2004] in Vena watershed, India. His research showed that there were negative significant correlations between *AWC* and *Dd* and *Sb*. Based on his research, it could be described that the area with intensive surface process tends to locate on a poor AWC site. The analysis reveals that the influence of drainage optometry is very significant in understanding the landform processes, soil physical properties and erosion characteristics.

There were significant correlations among independent variables that lead to a difficulty in choosing group of variables for analysis (Table 4). According to the situation above, multi regression analysis was applied by involving all variables to derive the best mathematical model. Mathematical models can be derived using step-wise method as presented in Table 5.

Table 5. Multi regression equation by using step-wise method

No	Mathematical model	*r*	R^2
1	Brc = 1.029 – 0.025 Dd	0.743	0.551
2	Brc = 0.996 – 0.022 Dd + 0.004 IR	0.838	0.702
3	Brc = 1.094 – 0.016 Dd + 0.003 IR – 0.338 CDI	0.887	0.786

The third equation was the best mathematical model in estimating *Brc* value by using significant variables. It was determined based on the highest determinant coefficient value (R^2= 0.786). This result was empirically relevant to the previous researches, in which the finding coincided, establishing and proving several relevance theories, such as:

Dd and *Sb* values indicate the storage capacity of watershed, and increment of watershed storage capacity affects on the higher quantity of base flow;

1. Soil infiltration capacity controls the water supply to groundwater storage, which then induces the baseflow condition, and increment of infiltration rate affects on the higher quantity of base flow;

2. Vegetation cover density influences the potency of evapotranspiration, and therefore generates the deterioration of groundwater storage and baseflow condition, and increment of canopy cover density affects on the higher quantity of base flow.

CONCLUSION

Based on the research undertaken on 30 watersheds in tropical monsoon area and quarter volcanic materials of Bali Island, there are two conclusions can be addressed as follows:

1. The enhancement of canopy cover density will generate downward baseflow recession coefficient, despite the fact that it is not a single factor and related to various physical aspects of watershed;
2. Drainage density (*Dd*), infiltration capacity (*IR*) and canopy density (*CDI*) were significance variables in determining the best mathematical model of canopy density and base flow recession coefficient correlation, that was:

$$Brc = 1.094 - 0.016Dd + 0.003IR - 0.338CDI$$

REFERENCES

Anwar, S. (2001), The Impact of Different Logging Treatments on Stream flow and Suspended Sediment Concentration in Central Kalimantan, Indonesia, *Thesis* submitted for the Degree of Doctor of Philosophy, Unpublished, The University of Edinburgh, (Scotland).

Bharati, L., K.H. Lee, T.M. Isenhart and R.C. Schultz (2002), Soil-Water Infiltration under Crops, Pasture, and Established Riparian Buffer in Midwestern USA, *Agro forestry Systems* 56: 249–257.

Bonell, M. and L.A. Bruijnzeel (2005), *Forests, Water and People in the Humid Tropics Past, Present and Future Hydrological Research for Integrated Land and Water Management*, Cambridge University Press, Cambridge.

Bruijnzeel, L.A. (2009), *Tropical Reforestation and Stream flow: the Need for a Balanced Account*, Vrije Universiteit, Amsterdam.

Bruijnzeel, L.A. (1990), *Hydrology of Moist Tropical Forests and Effects of Conversion: A State of Knowledge Review*, UNESCO International Hydrology Programme, Paris.

Bruijnzeel, L.A. (2004), Hydrological Functions of Tropical Forests: not seeing the soil for the trees? *Elsevier Agriculture, Ecosystems and Environment*, Science Direct, (104) 185–228.

Carreiras, J. M.B., M.C. Jose´ and J.S. Pereira (2006), Estimation of Tree Canopy Cover in Evergreen Oak Woodlands using Remote Sensing, *Forest Ecology and Management*, 223 5–53, doi: 10.1016/ j.foreco. 2005.10.056.

Chow, V.T., D.R. Maidment and L.W. Mays (1988), *Applied Hydrology*, McGraw-Hill Book Co, Singapore.

Davie (2002), *Fundamentals of Hydrology*, Routledge 2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN.

De Vries, J.J. (1975), *Groundwater Hydraulics*, Communication of Earth Sciences, Free Reformed University, Amsterdam.

Dou, L., M. Huang and Y. Hong (2008), *Statistical Assessment of the Impact of Conservation Measures on Stream flow Responses in a Watershed of the Loess Plateau*, China, Water Resource Management DOI 10.1007/s11269-008-9361-6.

Eckhardt, K. (2005), How to Construct Recursive Digital Filters for Base flows Separation, *Hydro Process*, 19, 507–515 (2005), DOI: 10.1002/hyp.5675.

Fan, L.Y. GAO., H. Brück and Ch. Bernhofer (2008), Investigating the Relationship between NDVI and LAI in Semi-arid Grassland in Inner Mongolia Using in - situ Measurements, Theory Appl. Climatology (2009) 95: 151-156. DOI: 10.1007/s00704-007-0369-2 .

Fetter, J.J. (1980), *Principles of Hydrogeology*, McGraw-Hill Book Co, New York.

Gordon, N.D., T.A. McMohan and B.L. Finlayson (1992), *Stream Hydrology: An Introduction for Ecologist*, John Wiley and Sons, New York.

Ilstedt, Ulrik, Malmer, Anders, Verbeeten, Elke, Murdiyarso, Daniel (2007), the Effect of Afforestation on Water Infiltration in the Tropics: A Systematic Review and Meta-Analysis, *Forest Ecology and Management*, 251 (2007) 45–51.

Kaimowits, D. (2004), Forests and Water: A Policy Perspective, *J For Res* (2004) 9:289–291, DOI 10.1007/s10310-004-0112-0.

Knapp, B. (2002), *Elements of Geographical Hydrology*, Unwin Hyman, London.

Kosugi, K. (1997), A New Model to Analyze Water Retention Characteristics of Forest Soils Based on Soil Pore Radius Distribution, *J. For. Res.,* 2:1-8.

Lee, R. (1980), *Forest Hydrology*, Columbia University Press, New York.

Martinuzzi, S., W.A. Gould, O.M.R. Gonzalez, A.M. Robles, P.C. Maldonado, N.P. Buitrago and J.J.F. Caban (2008), Mapping Tropical Dry Forest Habitats Integrating Landsat NDVI, Ikonos Imagery, and Topographic Information in the Caribbean Island of Mona. *Rev. Biol. Trop. Int. J. Trop. Biol.*, Vol. 56 (2): 625-639, June 2008.

Nagler P.L., E.P. Glenn, T. L. Thompson and A. Huete (2004), Leaf Area Index and Normalized Difference Vegetation Index as Predictors of Canopy Characteristics and Light Interception by Riparian Species on the Lower Colorado River, *Science Direct – Agricultural and Forest Meteorology*, DOI:10.1016/j.agrformet.-2004.03.008.

Nathan, R.J. and T.A. McMahon (1990), Aassessment of Automated Techniques for Base Flow and Recession Analysis, *Water Resources Research*, Vol. 26. No. 7, Pages 1465-1473, July 1990.

Newson, M. (1997), *Land, Water and Development, Sustainable Management of River Basin Systems*, Routledge, London.

Reddy, G.P.O., A.K. Maji and K.S. Gajbhiye (2004), Drainage Morphometry and Its Influence on Landform Characteristics in a Basaltic Terrain, Central India – a Remote Sensing and GIS Approach. *International Journal of*

Applied Earth Observation and Geoinformation, 6 (2004) 1–16.

Purwanto (1999), Erosion, Sediment Delivery and Soil Conservation in an Upland Agricultural Catchments in West Java, Indonesia, *PhD Thesis*, Vrije Universiteit te Amsterdam, Amsterdam.

Schipkan, F., J. Heimann and C. Leuschner (2005), Regional Variation in Canopy Transpiration of Central European Beech Forest, *Oecologia* (2005) 143: 260–270 DOI 10.1007/s00442-004-1798-6.

Schulz, E.F. (1976), *Problems in Applied Hydrology*. Water Resources Publication, Foat Collins, Colorado.

Seiler, K.P. and J.R. Gat (2007), *Groundwater Recharge form Run-off, Infiltration and Percolation*, Springer, Dordrecht.

Seyhan, E. (1975), *Fundamentals of Hydrology*, Geografisch Institute der Rijkuniversiteit, Utrecht.

Seyhan, E. (1977), *Mathematical Simulation of Watreshed Hydrologic Processes*, Geografisch Institute der Rijkuniversiteit, Utrecht.

Seyhan, E. and Keet (1981), *Multivariate Statistical Analysis, Application to Hydromorphometrical Data*, Communications of the Institute of Earth Sciences, Free Reformed University – Amsterdam.

Sri-Harto (1991), *Hidrologi Terapan*, Biro Penerbit Keluarga Mahasiswa Teknik Sipil, Fakultas Teknik UGM, Yogyakarta (in bahasa).

Soewarno (1984), Model for Estimating Flood Discharge of the Java Rivers, *Majalah Geografi Indonesia*, No. 14-15 Tahun 8-9.

Yue, S. and M. Hashino (2005), Statistical Interpretation of the Impact of Forest Growth on Stream flow of the Sameura Basin, Japan, *Environmental Monitoring and Assessment*, 104: 369–384.

Zavoianu, I. (1985), *Morphometry of Drainage Basin*, Editura Academiei.

Ward, R.C. (1975), *Principles of Hydrology*, McGraw-Hill Book Company, London.

Weert, V.D. (1994), *Hydrological Conditions in Indonesia,* Delft Hydraulics, Delft.