Characterizing infiltration of a tropical watershed from ALOSPALSAR data using the Green-Ampt infiltration model

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Abstract Land uses are known to influence hydrological processes such as infiltration within a watershed. This paper focuses on characterizing infiltration of a tropical watershed using ALOSPALSAR data based on four land-use types: grass, oil palm, shrub and rubber trees. The inversion of backscattering regression combined with a Green-Ampt infiltration model was applied to estimate soil moisture from ALOSPALSAR data and cumulative infiltration, respectively. The estimated soil moisture agreed with the observed data. The infiltration characteristics show the grass land use contributing the highest infiltration followed by oil palm, shrub and rubber land uses. Combined ALOSPALSAR data and the Green-Ampt infiltration model was a useful technique to characterize the temporal variability of infiltration.

Keywords soil moisture; infiltration; ALOSPALSAR data; Green-Ampt model

INTRODUCTION

Understanding the nature of water movement and its quantification is essential to solving a variety of hydrological problems (Ravi *et al*., 1998). This is very important in a tropical watershed when it comes to the wet season. Sometimes the process of water infiltration into the soil lessens and this can lead to increased flood occurrence in downstream areas. One of the methods to reduce this hazard is to evaluate the infiltration characteristic.

The Green-Ampt infiltration model is one of the physical models that describe the flow of water movement into the soil by assuming a piston-type profile with a well-defined wetting front (Ravi *et al*., 1998). The model consists of parameters that can be determined by field observations. These parameters influence the characteristics of the infiltration. One of the parameters is the initial soil moisture that can be estimated from ALOSPALSAR data. The study of infiltration in this paper places an emphasis on cumulative infiltration since the ALOSPALSAR data used is a single pass on a particular day.

The advantages of using ALOSPALSAR data are that it does not depend on sunlight and can penetrate through clouds and fill the lack of optical data. One of the unique aspects of ALOSPALSAR is that it uses the *L* band, which is a long wavelength that gives deeper penetration through the vegetation. Vegetation seems to be semi-transparent at this range (Jackson & Schmugge, 1991).

This paper evaluates the characteristic of cumulative infiltration in a tropical watershed located in Bekok catchment, Johor, Peninsular Malaysia, based on four different land-use types. About 70 soil samples were taken randomly to be validated with ALOSPALSAR data. However, these soil samples were plotted into only one plot that consists of all different land-use types to obtain the correlation between field data and ALOSPALSAR data. At the same time, the evaluation attempts the integration between ALOSPALSAR data and the Green-Ampt infiltration model to characterize the temporal variability of infiltration.

METHODOLOGY

This study is done in three phases. In the first phase, soil moisture information was estimated from ALOSPALSAR data based on a backscattering regression model (Holah *et al*., 2005). The second phase is optimizing the Green-Ampt infiltration model's parameters (Ravi *et al*., 1998) by minimizing the sum of squares error between observed and estimated cumulative infiltration. The

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soil texture classification in this paper is based on USDA soil texture classification (Soil Survey Division Staff, 1993). The Green-Ampt model (equation (1)) is the result of integration of Darcy's law from Ravi *et al.* (1998).

$$\frac{K_s}{\theta_s - \theta_i} t = L_f - \left(h_0 - h_f\right) L_n \left(1 + \frac{L_f}{\left(h_0 - h_f\right)}\right) \tag{1}$$

where K_s is saturated soil hydraulic conductivity, h_0 is soil water pressure head at the surface, h_f is the soil water pressure head at wetting front, L_f is the length of wetting front, θ_s is saturated water content, θ_i is the initial water content, and t is time.

In the final phase, the estimated soil moisture from ALOSPALSAR data is given as the input of initial soil moisture in Green-Ampt infiltration model.

RESULTS AND DISCUSSION

Soil moisture estimation from ALOSPALSAR data

Figure 1 (a) shows the calibration of backscattering coefficient from ALOS PALSAR data to estimate soil moisture. The observed and estimated soil moisture indicated a good relationship with coefficient of determination, $R^2 = 0.708$.

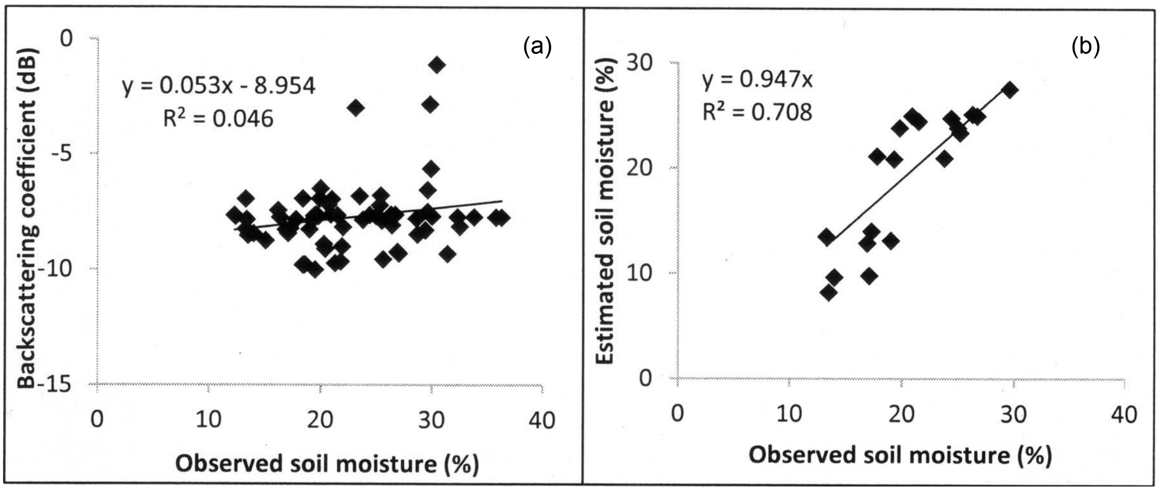

Fig. 1(a) The relationship between field soil moisture observation and backscattering coefficient of ALOS PALSAR; and (b) the comparison between the estimated and the observed soil moisture.

Field observation of cumulative infiltration at different land use types

Table 1 shows the observation results of physical properties of different land use types. Based on the USDA soil texture classification, the soil in the catchment area was dominated by clay with greater than 40% of clay occurring in the soils except for oil palm area. Oil palm land use was dominated by sand, with 72% of sand occurring in the soil.

Of the four land uses, grass has the highest saturated soil water content due to its particle size distribution being dominated by clay followed by shrub and rubber respectively. Mitchell (1993) and Saxton & Rawls (2006) in Askari *et al.* (2008) stated that the smaller soil particles that occurred, the larger the contact area among its particles.

In contrast, with contribution of the lowest percentage of clay, oil palm has similar saturated soil water content as rubber. It might be due to organic matter that occurs in this land-use type. According to Emerson (1995) in Askari *et al.* (2008) the occurrence of higher soil organic matters not only will strengthen the soil aggregate, but will also enhance soil capacity in holding and storing water.

Table 1 Observation of soil physical properties of four USDA texture types for different land use.

Land use	Observation						
	% Clay	% Silt	% Sand	Soil texture	Bulk density ρb (g/cm^3)	Θs (cm^3/cm^3)	Θi (cm^3/cm^3)
Shrub	44	14	42	Clay	1.51	0.543	0.261
Rubber	42	19	39	Clay	1.15	0.483	0.218
Oil palm	23	5	72	Sandy clay loam	1.74	0.484	0.318
Grass	53	33	14	Clay	1.99	0.588	0.564

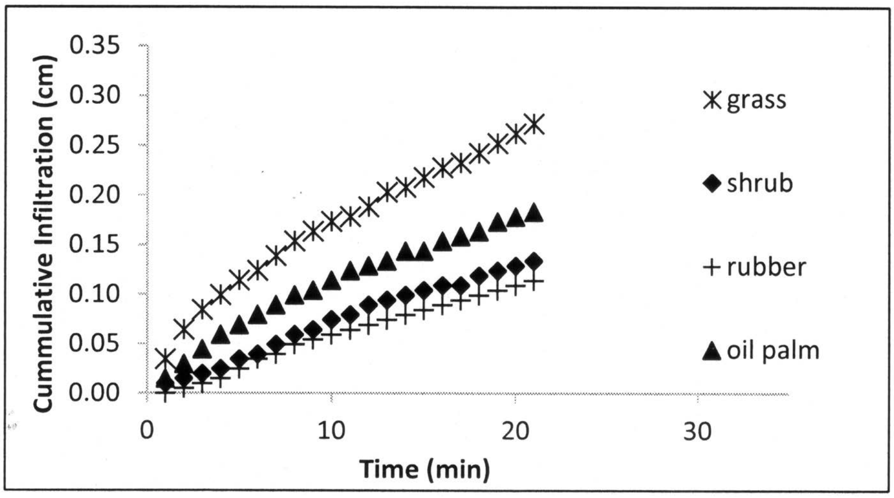

Fig. 2 Time dependence of cumulative infiltrations for different land use types.

Figure 2 shows the time dependence of cumulative infiltration in different land-use types. Grass has the highest cumulative infiltration among the land uses, followed by oil palm, shrub and rubber. This phenomena is equal to the difference between saturated water content (θs) and initial water content (θi) since both parameters influenced each other, especially for grass which has the lowest difference compared to shrub which has the highest difference. Higher differences between θs and θi indicate a dryer soil while lower differences between θs and θi indicate a wetter soil. As stated by Shakesby *et al.* (2000), a wetter soil can lead to high cumulative infiltration while dryer soils can lead to low cumulative infiltration.

Optimization of Green-Ampt parameters for different land-use types

Figure 3 shows that clay soil under rubber was the highest saturated hydraulic conductivity followed by sandy clay loam under oil palm and clay under shrub. This is due to the contribution of silt and sand particles (58%) and low bulk density (see Table 1). Although sandy clay loam under oil palm has a high fraction of sand, it also has a low fraction of silt and the highest bulk density compared to rubber and shrub. This caused the saturated hydraulic conductivity of oil palm to be below rubber.

Clay under shrub land use, with a contribution of silt and sand (56%) (Table 1) has the lowest saturated hydraulic conductivity amongst the rubber and oil palm land uses. Although the fraction of sand under shrub was higher than rubber, the fraction of silt was low, with a high bulk density which resulted in the saturated hydraulic conductivity of shrub being lower than rubber.

There is an interesting phenomena under grassland which has the highest clay fraction (Table 1). It has the highest saturated hydraulic conductivity. This phenomena is no longer caused by pore size and its distribution, but could be due to the contribution of the mineral content of clayey soil. This phenomena might be strongly influenced by montmorillonitic mineral content of

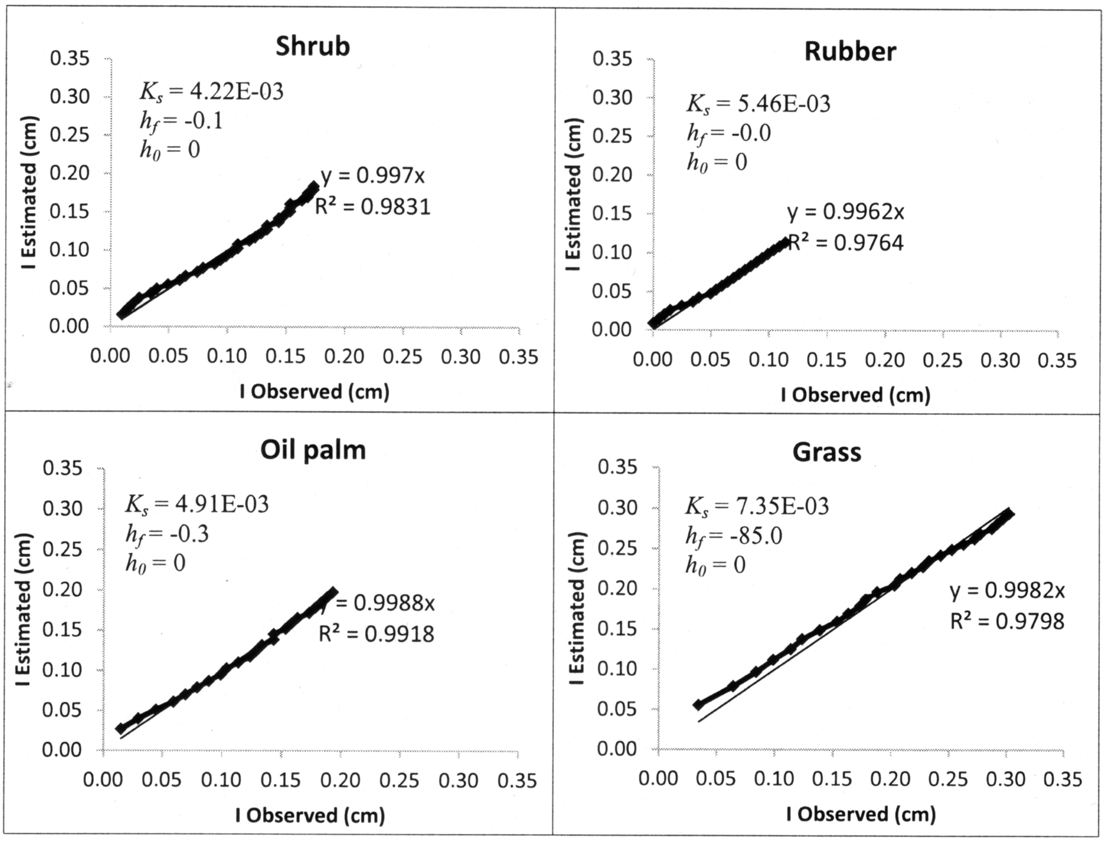

Fig. 3 The comparison between observed and estimated infiltration for four different land use types.

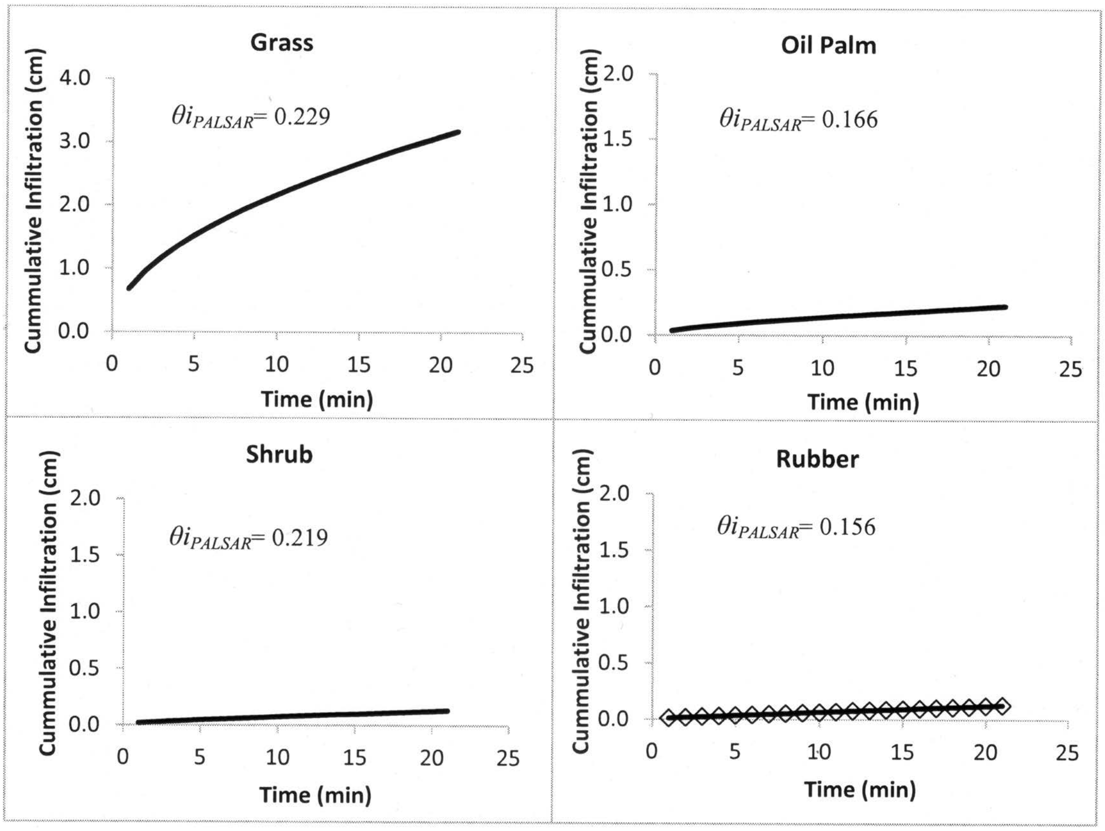

Fig. 4 Simulation of cumulative infiltration estimated from PALSAR soil moisture data.

the clayey soil. This is supported by the observation of montmorillonitic mineral by Wakindiki & Ben-Hur (2002) using a scanning electron microscope which indicated that montmorillonitic soil had a thicker crust compared to small particles, with a very developed washed-in zone underneath or large ones with fine material between them.

Simulation of Green-Ampt infiltration model at different land use types using ALOSPALSAR data

The estimated initial soil moisture data was obtained from ALOSPALSAR data with the same coordinates as the field observation data but at different dates. Figure 4 shows the simulation of cumulative infiltration in four different land-use types within 21 minutes. Grass indicated the highest cumulative infiltration followed by oil palm, shrub and rubber. This simulation graph shows a similar pattern to the time dependence field cumulative infiltration graph, in Fig. 2.

CONCLUSION

The result of soil moisture estimation from ALOSPALSAR data has shown a good correlation with the observed soil moisture. The characteristic of infiltration for all land use in the tropical area shows that grass has the highest infiltration followed by oil palm, shrub and rubber. The integration of ALOSPALSAR and the Green-Ampt infiltration model is a useful technique to characterize the temporal variability of infiltration in a tropical watershed.

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