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Effects of Forest Degradation on Forest's Soil Water Retention in Northern Vietnam

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Abstract. This study characterized the forest soil water retention of four forest types in Thuong Tien Natural Reserve, Northern Vietnam. Forty forest plots were designed to measure forest structure, topography, and soil properties. Daily soil moisture of 40 plots and rainfall were collected in a period of 60 consecutive days. Multi-linear regressions were used to inspect the relationship between forest structures, soil porosity and forest soil moisture. The environmental factors having strong effect on forest soil moisture are litter cover, vegetation ground cover, and soil porosity. Forest soil moisture can be predicted by the two regression models. First, prediction model of soil moisture for a rainy day (R^2 =0.55 – 0.81). Second, prediction model of soil moisture for a no rainy day (R^2=0.52 – 0.83). Main predictors of these models are rainfall, antecedent soil moisture and time interval (days). The root square means error (RSME) of the predicted values of the models is 2.03%. Forest soil water retention, a function of soil moisture, soil depth and bulk density, varies among four forest types. The capability to retain water of forest types ranks from moderate forest (401mm), in turn, rehabilitation forest (350mm), poor forest (346mm), and mixed grass + shrub (249mm). Forest soil water retention also is monthly variability, mainly depending on annual rain regime. The highest capability of water stored in soil is in August, and the lowest one is in February.

Keywords: forest hydrology, soil water retention, soil moisture, forest degradation.

1. Introduction

It has long been recognized that deforestation has important consequences for its hydrological behavior. Changes in forest structure (e.g., canopy closure, ground cover) directly or indirectly can cause changes in interception of precipitation, evapotranspiration and physical properties of soil (e.g., depth, porosity). These changes seriously influence water infiltration into the soil and soil water retention capacity. Thus, effects of forest disturbances or conversions on hydrological roles of forest have been attracted considerable attention from the public since the last centuries.

A review of 94 catchment experiments by Bosch and Hewlett (1982) [1] shows that changes in vegetation resulted in changes in water yield. Yield increases due to deforestation or decreases due to reforestation. Most of scientific studies in North America have conclusions that reducing both peak and low flows concerned with felling effects (Robinson et al., 2003) [2]. In more detail, for a 10%

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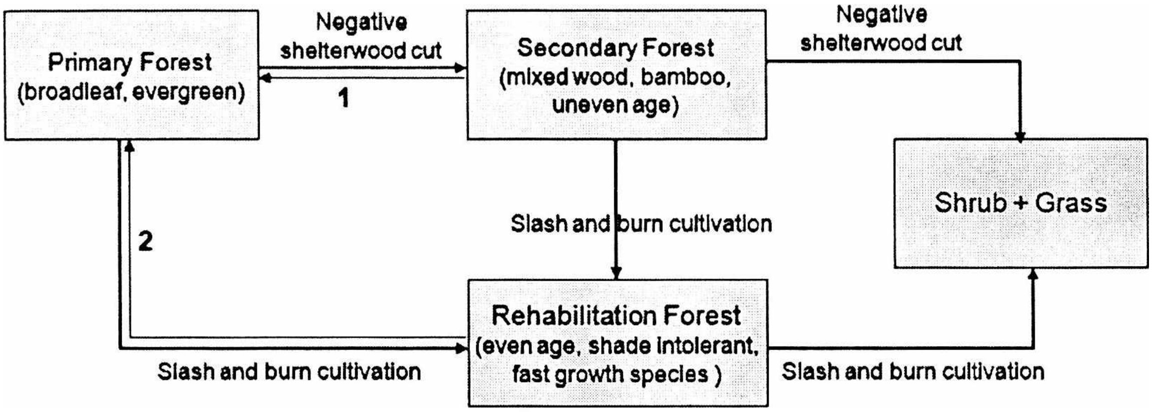
reduction in cover, the yield from conifer forest increased by some 20-25mm, whereas that for eucalyptus type forest only 6mm (Salin et al., 1996) [3]. Runoff yield annually increased 30% due to the destruction of forest after a wildfire (Lavabre et al., 1993) [4].

On the other hand, Andreassian (2004) [5] note that deforestation increases low flow are shorten by recovery of forest causing flow to cease. Reforestation in the harvested areas caused the water yield to return to pre-harvesting levels within 8 years, and storm peak flows, quickflows, and low flows back to original levels within 10 years (Fahey, 1997) [6]. Reforestation and soil conversion are able to reducing the increase of peak flow and storm flow associated with soil degradation (Bruijnzeel, 2004) [7].

Changes in forest structure also cause changes in water yield. At a small scale of catchment less than 1km^2, water yield increases after replacing tall vegetation by a shorter one and vice versa (Bruijnzeel, 2004) [7]. A decrease in total basal area resulted in an increase total stream flows, direct runoff, and ground water recharge for six dormant and growing seasons during 1968-1971 (Bent, 2001) [8].

In Vietnam, forest coverage decreased from 43% in 1943 to about 28.8% in 1999. Vietnam's deforestation is consequences of high population growth, rapid industrialization and urbanization, and inappropriate management policies during this period. Between 1990 and 2005, Vietnam lost a staggering 77.8 percent of its primary forests, leaving it only 85,000 hectares of old growth forest. However, the forest coverage is recovering. Since 1999, the area covered by plantations has expanded from 1.47 million hectares to 2.55 million hectares (FPD, 2008) [9]. Deforestation has simplified vegetation in terms of diversity and structure, leading to land degradation (Lal, 1996) [10]. Figure 1 is a simple diagram representing degradation of primary forest by the human impacts in the northern of Vietnam (Phuong, 1970) [11].



(1) a long life shade tolerant species (e.g., *Erythrophloeum fordii)* forest, if experiencing repeatedly negative selective cutting, will be, in turn, forest with complex mixed wood species (i.e., long and short life species, shade tolerant and intolerant species); mixed wood trees and bamboo forest; shrub and grass; (2) if primary forest experienced rotation of slash and burn cultivation, it will be, in turn, forest of even age, fast growth and shade intolerant of some dominant species; forest of shorter life wood species + bamboo; shrub and grass. Without human impacts, forest can rehabilitate to the first stage from mixed wood + bamboo stage (Phuong, 1970) [11].

Figure 1. Simply negative secondary succession of natural forest in the northern of Vietnam.

Vietnam's deforestation has been blamed for worsening soil erosion and floods. Few studies on forest hydrology indicated that the hydrological roles of forest are different from those of the other cover types. Phien and Toan (1998) [12] demonstrated that runoff from forests was 2.5 - 27 times smaller than runoff from agricultural crops. Runoff measurement observed in natural forests was 3.5 to 7 times less than that in plantation forests (Nganh et al., 1984 [13]; Hai, 1996 [14]) . The infiltration rate in a three storey natural forest was measured at 16.8 mm per minute, while it was reported at 10.2 mm per minute in forests restored after shifting cultivation, and 2.1 mm per minute for shrub and grass land (Niem, 1994 [15]; Tuan, 2003 [16]).

The general objective of this study is to identify effects forest degradation on soil water retention capacity. To meet this objective, the study will select 4 dominant forest types in the research areas (e.g., secondary forests with moderate and low total tree volume; rehabilitation forest; and grass + shrub) and estimate their soil water retention. Selected forest types are representative for different levels of forest degradation in a same area. Forest's soil water moisture will be analyzed in relation to the environmental factors (forest structure, soil porosity, etc.). This study will also build up prediction models of soil water moisture for corresponding forest type.

2. Methodology

2.1. Study sites

The study sites are located in a watershed of Thuong Tien river, Hoa Binh province, (roughly $105^0 20'$-$105^0 40'$ E, $20^0 30'$-$20^0 40'$ N), about 60km in the western of Ha Noi, Vietnam. The watershed lies between 200m and 1100m elevation; average slope and slope length are from 25^0 to 30^0, and from 1km to 1.5 km, respectively. Soils are brown Feralit with fined-textured and well-drain, derived from Bazich bedrock. Average soil depth is greater than 80cm.

The climate is monsoon tropic. The dynamic monsoon circulation patterns produce two main seasons, a dry, cool winter and a warm, wet summer. The rainy season begins in May and lasts until the end of September. Average annual rainfall is 2263mm. Rainfall is highly seasonal, with approximately 80% of rain falling in rainy season. Average annual air temperature is 24^0C, mean monthly air temperature ranges from 5^0C in January to 39^0C in July. Average annual air humidity is 84%, with low variation, the highest monthly air humidity is 88% in September and the lowest one is 82% in May (HMDC, 2009) [17].

Vegetations are mainly secondary evergreen broadleaf forests, some parts are rehabilitation forests, shrub, grass, and slash and burn cultivation, these classifications are based on forest's structures, e.g., composition, tree volume, age, etc. For example, total tree volume is ranked from high to low, so called "rich forest", "moderate forest", and "poor forest", respectively; Young, even age forest rehabilitating from sifting cultivation or clear cutting is so called "rehabilitation forest". The current cover types research areas are results from human activities (i.e., selective or clear cutting) in the 20^{th} century, they distributed separately in the whole research areas (FPD, 2008) [9].

2.2. Data collection

Data were collected in 40 plots, 10 plots for each forest types. The plot size is $400m^2$ (20m x

20m). The system of plots were predefined on the digital map and navigated on the field by GPS. The location of plots were representatively selected, they are evenly distributing on three types of topography (convex, concave, and plane), representing for variations of slope and elevation in watershed, and setting up far from top-slope at least 50m. In each of forest type, the distance between plots is from 200m to 400m. Information in each plot was measured and collected as following:

- *Forest structures:* DBH (cm); height (m); canopy closure (%); vegetation ground cover (%); dried litter cover (%); density (trees/ha). Basal area (m^2/ha) and tree volume (m^3/ha) are calculated from DBH and height.

- *Soil moisture (%):* soil samples were daily taken at different levels of soil depth (0-10cm; 20-30cm; 40-50cm; 80-100cm; and >100cm) from 8h30' to 9h30' in 60 consecutive days (from May 15 to July 15, 2007). Each sample was marked and stored in a plastic bag. Soil moisture was identified in laboratory (Manoj, 2011) [18].

$$W(\%) = \frac{(W_1 - W_2)}{W_2} * 100 \quad (1)$$

Where: W soil moisture (%); W_1 weight of soil sample before oven drying (g); W_2 weight of soil sample after oven drying (g).

- *Soil porosity (%):* a bulk density pipe is used to collect soil samples at different given soil horizon (0-10cm; 20-30cm; 50-60cm). Soil porosity is calculated from soil bulk density (g/cm^3) and soil particle density identify (g/cm^3) in laboratory (Manoj, 2011) [18].

$$Porosity(\%) = \left(1 - \frac{BulkDensity}{ParticleDensity}\right) * 100 \quad (2)$$

- *Soil water retention (mm):* total amount of water retaining within soil, it is a function of soil depth, bulk density, and soil moisture (Manoj, 2011) [18].

$$P_{W_r}(mm) = SoilDepth * BulkDensity * SoilMoist. \quad (3)$$

Where: P_{W_r} soil water retention (dm); Soil depth (mm); bulk density (g/cm^3); soil moisture (%)

3. Results

3.1. Forest distributions and its structures

Total research areas are 5611 ha, including 10 familiar cover types. Vegetation covers are classified based on their structure, time of rehabilitation and magnitude impact of human (FPD, 2008) [9]. The four main cover types are moderate forest, poor forest, rehabilitation forest, and grass+shrub. They accounted for 92.8% of the research areas (5207ha), the largest cover type is poor forest (26.5%), the next largest cover types are rehabilitation forest (24.5%), moderate forest (23.5%), and shrub + grass (18.3%). They are selected to estimate relationship between forest structure and soil water retention.

Moderate and poor forests are mostly distributed on elevation above 500m. The lower areas are rehabilitation forest and grass+shrub. Forests also mainly concentrate in the slope higher 15^0. The data show that when forest spatially distributed on a higher elevation and slope, they tend to have a diversified structure and a higher volumes (moderate forest vs. poor forest). This can be explained by magnitude of human impacts (i.e., shelterwood cutting, clear cutting) since the 1980s in the 20^{th} century. Forest structure characteristics are averaged out in Table 1. Each of forest types has its own structures and is different from those of the others.

Table 1. Averaged forest's structure indices of 10 plots for the 4 forest types

Cover types	Plots	Density (trees/ha)	DBH (cm)	Height (m)	Volume (m^3/ ha)	CC (%)	GC (%)	LC (%)
Moderate forest	10	533	20.0	15.5	131.4	64.3	51.4	72.8
Poor forest	10	360	16.5	14.6	58.3	51.7	52.4	59.1
Rehabilitation forest	10	596	14.7	12.8	64.5	51.5	52.0	49.1
Grass+shrub	10			0.80			76.7	71.5

** CC: canopy cover; GC: ground cover; LC: litter cover*

Moderate forest (moderate tree volume) is secondary natural forest with low human impact. Therefore, its tree volume, DBH, and height are the highest among forest types. It is relatively species richness. Density ranges from 425 to 693 trees/ha, canopy closure is approximately 65%; DBH and height range from 18cm to 24.3cm and from 14.8m to 17m, respectively. Grass and shrub ground cover is 51%.

Poor forest (low tree volume) is also secondary natural forest. It has been remained and recovered from heavily selective cutting, compared to the impact of moderate forest. It explains for that all poor forest's structure indices are smaller than those of moderate forest. Density ranges from 219 to 521 trees/ha, canopy closure is approximately 52%; DBH and height range from 12.3cm to 21.8cm and from 11.9m to 16.5m, respectively. Grass and shrub ground cover is 54%.

Rehabilitation forest is areas that regenerated from clear cutting forest or slash and burn cultivation. Trees are young, density ranges from 412 to 773 trees/ha, higher than those of moderate forest and poor forest; canopy closure is about 51%; DBH and height range from 12.1cm to 17cm and from 10.9m to 14.9m, respectively. Grass and shrub ground cover is 51.7%.

The mixed grass+shrub areas were results from a long term and intensive process of clear cutting and sifting cultivation. This type has no canopy that is explaining for why its ground cover is the highest among forest types (75% vs. 50%). The average height of grass + shrub is 0.8m.

3.2. Forest soil moisture and soil porosity

** Forest soil moisture*

Forest soil moistures vary among forest types (Fig. 2). Moderate forest has the highest soil moisture (35.8%), ranking, in turn, is poor forest (32.2%), rehabilitation forest (30.4), and grass+shrub (25.3%). However, the differences in soil moisture between forest types are not considerable, the largest difference is between moderate forest and grass+shrub (10.5%), and the smallest ones is between poor forest and rehabilitation forest (1.8%).

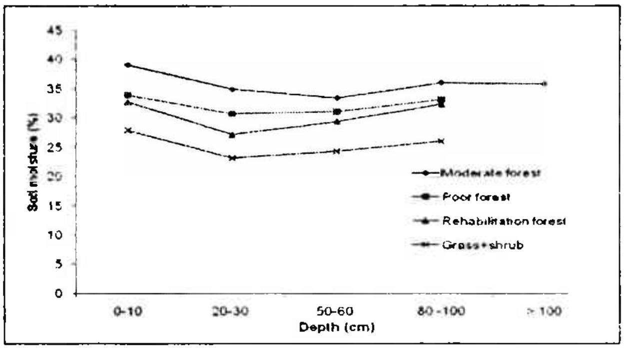


Figure 2. Changes in averaged soil moisture on depths for 4 forest types during a period of 60 consecutive days (May 15 - July 15, 2007).

For each forest type, average soil moistures are unstable among soil depths. Generally, soil moisture is the highest in top soil (0-10cm), decreasing to the lowest in depth of 20-30cm, and slightly increasing in depth of 50-60cm and so on.

Under the effect of rainfall, the tendentious changes of topsoil moisture in all forest types are fairly similar. Topsoil moisture apparently increases after raining and decreases on the next consecutive days (Fig. 3). Rate of increases depends on the magnitudes of antecedent topsoil moisture and rainfall. However, when topsoil moisture is maximum saturated, it is unrelated to rainfall.

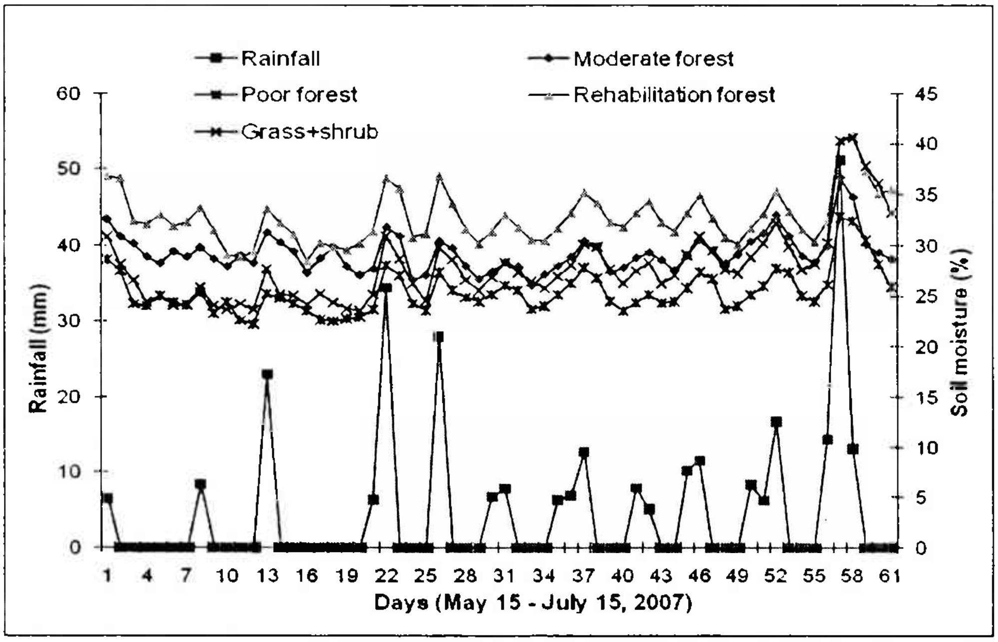


Figure 3. Changes of topsoil moisture and rainfall during a period of 60 consecutive days (May 15 – July 15, 2007).

It is very much the same as the previous results. Most of time, the highest and the lowest values of topsoil moisture are in moderate forest and grass + shrub, the averaged value is 39% and 27.9%, respectively. Those of poor forest and rehabilitation forest are approximately equal to 33%. The variability in soil moisture is mainly caused by the variability of forest structures among forest types.

** Forest soil porosity*

Porosity is a measure of the amount of pore space in a soil, it influences the movement of water and defines amount of water stored in a soil (Kimmins, 2004) [19]. Soil porosity varies among forest types. At any soil depth, soil porosities gradually decrease from moderate forest to grass + shrub. For each of forest type, soil porosity decreases from topsoil to the lower depth (Fig. 4).

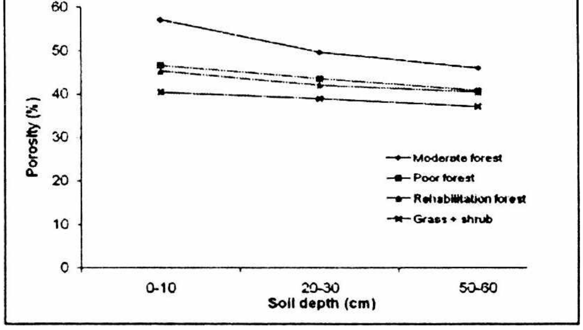


Figure 4. Changes in averaged soil porosity on depths for 4 forest types.

3.3. Effects of environmental factors on forest soil moisture

Forest soil moistures are spatially different over the study sites. It is able to be explained by changes in environmental factors among forests. From the data of 40 plots, multiple linear regressions were used to inspect these relations.

As shown in Table 2, all regression models are significant (P val. <0.05), and substantial relationship (R^2 >0.70). The best goodness of fit model is in rehabilitation forest (R^2=0.85). Those of moderate forest, poor forest, and grass + shrub are similar (R^2=0.78). The weakest fit of model is in general equation for all cover types (R^2=0.67).

Table 2. Regression equations of soil moisture and environmental factors

Equations		R^2	Adj. R^2	P val.
$W^a = 61.89 + 0.46*V - 3.98*LC$	(4)	0.78	0.72	0.005
$W^b = 39.85 - 0.131*GC - 0.188*LC + 0.223*Po$	(5)	0.78	0.68	0.019
$W^c = 19.93 + 0.282*Po$	(6)	0.85	0.83	0.001
$W^d = 41.01 - 0.214*SL - 0.297*GC + 0.305*Po$	(7)	0.78	0.67	0.020
$W^e = 26 - 0.084*GC - 0.072*LC + 0.355*Po$	(8)	0.67	0.64	0.001

* W: soil moisture (%); V: tree volume (m^3); LC: litter cover (%); GC: ground cover (%); SL: slope (%); Po: soil porosity (%); * all independent variables are significant at α =0.05
^{a} Eq. for moderate forest; ^{b} Eq. for poor forest; ^{c} Eq. for rehabilitation forest; ^{d} Eq. for mixed grass+shrub; ^{e} Eq. for all cover types.

Litter cover is only not significant in equation (6) and (7), and ground cover is not significant in equation (4), and (6), respectively. These variables are indirectly proportional to the soil moisture. It is contrary to other researcher's conclusions (Quynh, 1996) [20] that litter cover and ground cover may reduce soil evaporation, thus keep more moisture for the soil. In this study, those inverse relations may be explained as that small rainfall during study period was retained in the covers, and as a result soil is drier compared to that of an area having lower covers.

Porosity is significant at 4 of 5 equations. It is directly proportional to the soil moisture, because the higher porosity may be increasing water retentive capacity of soil. Both tree volume and slope variables are found to be just significant for an equation, tree volume is in direct relationship to the soil moisture in equation (4), and inversely to the slope in equation (8).

Standardized coefficients (β) of litter cover and porosity are usually higher than those of other variables in a same equation, indicating that litter cover and porosity are the most important variable affecting soil moisture.

Other independent variables (e.g., diameters, height, and canopy closure) are not present in all equations, explained by the two reasons. First, they do not correlate with soil moisture, and are being removed in model selection process (stepwise). Second, there is colinearity among independent variables. For example, diameter and height are highly correlated with tree volume, their correlation coefficients (r) are 0.87 and 0.78, respectively.

3.4. Soil moisture Prediction Models

Forest soil moisture is predicted by two models. The first model is the prediction of soil moisture for rainy days (1), and the second model is the prediction of soil moisture for no rainy day (2).

* *Prediction Models for rainy days (1)*

The prediction model of soil moisture for a rainy day is a function of rainfall, antecedent soil moisture, and other environmental factors. As shown in the Table 3, all prediction models are highly significant (P val. <0.05), their coefficients of determination are substantial (R^2 > 0.5). The two best goodness of fit models are in rehabilitation forest (eq. (11), R^2=0.83), and grass + shrub (eq. (12); R^2=0.81), respectively. The weakest goodness of fit model is in poor forest (eq. (10); R^2=0.55).

Table 3. Soil moisture prediction models for rainy days of four forest types

Equations		R^2	P val.[c]
$W_{RD}{}^a = 43.96 + 0.288{*}P_m + 0.239{*}W_{BR} + 0.0036{*}CC + 0.0024{*}GC + 0.0014{*}LC + 0.012{*}Po - 0.01{*}SL$	(9)	0.61	0.001
$W_{RD}{}^b = 44.72 + 0.249{*}P_m + 0.0095{*}W_{BR} + 0.0017{*}CC + 0.0032{*}GC + 0.0024{*}LC + 0.02{*}Po - 0.013{*}SL$	(10)	0.55	0.001
$W_{RD}{}^c = 22.30 + 0.223{*}P_m + 0.501{*}W_{BR} + 0.0018{*}CC + 0.0041{*}GC + 0.0015{*}LC + 0.011{*}Po - 0.0062{*}SL$	(11)	0.83	0.001
$W_{RD}{}^d = 20.34 + 0.246{*}P_m + 0.404{*}W_{BR} + 0.0019{*}GC + 0.0023{*}LC + 0.0072{*}Po - 0.0071{*}SL$	(12)	0.81	0.001

W_{RD}: soil moisture after raining (%); W_{BR}: antecedent soil moisture - before raining (%); P_m: rainfall (mm); CC: canopy closure (%); LC: litter cover (%); GC: ground cover (%); SL: slope (%); Po: soil porosity (%)
[a] Eq. for moderate forest; [b] Eq. for poor forest; [c] Eq. for rehabilitation forest; [d] Eq. for mixed grasses, shrub;
[e] P val. are significant at α < 0.001.

In all regression equations, soil moisture after raining is directly proportional to rainfall, soil moisture before raining, canopy closure, ground cover, litter cover, and porosity (β>0), whereas, it is inversely related to slope (β<0).

Rainfall and soil moisture before raining are the two independent variables having the strongest effect on dependent variable (W_{RD}), their standardized coefficients (β) are always higher than those of other independent variables in a same equation. The effects of canopy closure, ground cover, litter cover, porosity, and slope on soil moisture after raining are minimal, in all equations their regression coefficients are less than < 0.01.

* *Prediction Models for no rainy days (2)*

This model (2) is applied to predict soil moisture of no rainy days, when soil moisture of an antecedent rainy day is known, predicted by the model (1). The model (2) is a multilinear regression of soil moisture, interval time (days), and other environmental factors. As listed on the Table 4, all prediction models (2) are highly significant at α=0.05. The goodness of fit of model for each of forest type ranked, in turn, from grass+shrub (R^2=0.83), to rehabilitation forest (R^2 = 0.79), poor forest (R^2 = 0.74), and moderate forest (R^2 = 0.52). The goodness of fit of models (2) is relatively similar to that of the previous model (1).

Table 4. Soil moisture prediction models for no rainy days of four forest types

Equations		R^2	P val.[e]
$W_{AR}{}^{a} = 40.05 + 0.204*W_{RD} - 26.23*ND^{0.1} + 0.138*CC + 0.185*GC + 0.0056*LC + 0.101*Po - 0.044*SL$	(13)	0.52	0.001
$W_{AR}{}^{b} = 53.45 + 0.321*W_{RD} - 32.02*ND^{0.1} + 0.079*CC + 0.098*GC + 0.019*LC + 0.035*Po - 0.261*SL$	(14)	0.74	0.001
$W_{AR}{}^{c} = 26.36 + 0.535*W_{RD} - 25.66*ND^{0.1} + 0.154*CC + 0.161*GC + 0.036*LC + 0.038*Po - 0.061*SL$	(15)	0.79	0.001
$W_{AR}{}^{d} = 24.40 + 0.415*W_{RD} - 24.78*ND^{0.1} + 0.0064*GC + 0.034*LC + 0.121*Po - 0.295*SL$	(16)	0.83	0.001

W_{AR}: soil moisture of predicted day - a following day after raining (%); W_{RD}: antecedent soil moisture of a rainy day (%); ND: number of days from a rainy day to the predicted day; CC: canopy closure (%); LC: litter cover (%); GC: ground cover (%); SL: slope (%); Po: soil porosity (%)

[a] Eq. for moderate forest; [b] Eq. for poor forest; [c] Eq. for rehabilitation forest; [d] Eq. for mixed grass, shrub

[e] P val. are significant at $\alpha < 0.001$.

In all models (2), the prediction soil moisture (W_{AR}) are directly proportional to the earlier soil moisture (W_{RD}), canopy closure, ground cover, litter cover, and porosity ($\beta>0$), whereas, it is inversely related to time and slope ($\beta<0$).

The most influent variables on the prediction is antecedent soil moisture and time interval, their standardize coefficient (β) are always higher than those of other independent variables. As known, all independent variables, except time (days), are constants for a forest types (e.g., canopy closure, slope, etc.). Thus, the predicted soil moisture will gradually reduce over time, mostly depends on beginning soil moisture and predictive time interval. Reductive rate of soil moisture after rain mainly depends on standardized coefficient of time ($\beta<0$). Compared these coefficients among four forest types, it shows that the biggest soil moisture reduction is in poor forest, those of other forest types are similar.

** Model validation*

The predicted soil moisture values are compared with actual data to determine which model might better represent prediction for the independent responses. The model verification and validation are based on root square mean error (RSME), equation (17). The RMSE is expected to be as small as possible.

$$RSME = \sqrt{\frac{(PredictedValue - ActualValue)^2}{\#Values}} \quad (17)$$

In this study, due to lack of data, only models for moderate forest are validated. 70 soil samples of moderate forest were daily collected from August 20 to October 31, 2007. These samples are independent and not used to establish the model. The corresponding predicted soil moisture values were also calculated. The results show that equation (9) and (13) are the two models giving the lowest RSME (2.03%). This indicates that the most statistically significant models (Table 3, 4) are also the most validation models.

3.5. Forest soil water retention

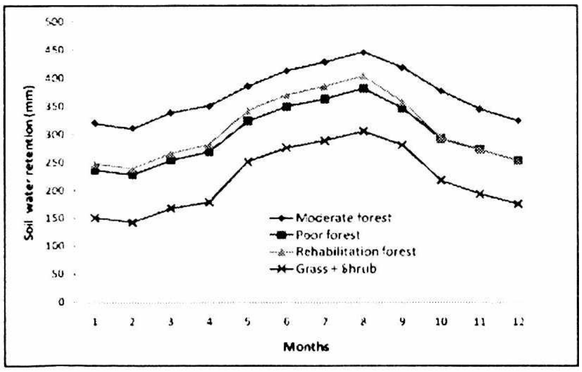
Average soil water retention during study period was estimated for each forest type (Table 5). The results show that it varies among forests, and depends on soil depth, bulk density, and soil moisture, respectively. The highest capabilities of soil water retention in moderate forest (401 mm), the lowest ones is in grass+shrub (350 mm). Those of poor forest and rehabilitation forest are approximately similar.

Table 5. Averaged forest soil water retention from May 15 to July 15, 2007

Cover types	Soil depth (m)	Bulk density (g/cm^3)	Soil moisture (%)	Soil water retention[a] (mm)
Moderate forest	0.85	1.32	35.8	401
Poor forest	0.78	1.38	32.2	346
Rehabilitation forest	0.80	1.44	30.4	350
Grass + shrub	0.67	1.47	25.3	249

[a] Soil water retention is calculated based on equation (3)

Soil water retention is not only varying among forest, but also changing monthly (Fig.5).



* Rainfall and its distribution of 2006 was used to estimated monthly soil water retention (HMDC, 2010) [13]; Soil moisture (%) estimated by applying the two corresponding prediction models. It is estimated as daily timescale, and monthly averaged as above; Soil water retention (mm), calculated by equation (3).

Figure 5. Monthly distribution of soil water retention of forests.

For a specific forest type, soil depth, bulk density are unchangeable, so the monthly variability of soil water retention strongly depends on the variability of soil moisture which is influenced by quantities and distribution of annual rainfall. Forest soil water retention both monthly and spatially varies among forest types. Generally, soil water retention is the highest in moderate forest and the lowest in grass + shrub. Those of other forest types are in the middle. At monthly timescale, the trends of soil water retention of four forest types are similar. For a given forest type, soil water retention got the smallest value in February, gradually increases to peak in August, and reduce until January next year.

4. Discussions

One of the interesting results obtained in this study is that soil moisture is decreasing, in turn, from moderate forest to poor forest, rehabilitation forest, and grass + shrub. Meaning that the lower level of forest degradation, the higher value of forest soil moisture. As known, forest soil moisture defines soil water storage which strongly influences storm flows (Scott et al., 2005) [21]. One may think that these results are contrary to historical scientific studies in North America, Australia that deforestation (e.g., clear cutting, thinning, and conversion) increases water yield, stream flow, because of a reduction in interception and evapotranspiration (Beschta et al., 2000 [22]; Ruprecht at al., 1988, 1990 [23, 24]; Borg et al., 1988 [25]). However, their results may be not similar to those of other places because of variation in forest management activities, climate, and physiography. As indicated by Robinson et al. (2003) [8], in Europe changes in forest cover at a regional scale have a relatively small effect on peak and low flows.

On the other hand, the contrary results in this study can be explained as following. First of all, the study did not quantify water yield or stream flows of corresponding forest types. Although, it is generally accepted that soil water storage capacity affects lowflows or stormflows (Scott et al., 2005) [21]. It is not enough scientific evidences from this study to conclude that moderate forest, having the highest soil water retention capacity, can enhance baseflows or lowflows better than those of the other forest types. Furthermore, more water infiltration into the soil (i.e., high soil moisture) may not relate to an increase in water yield, because the difference in interception loss and evapotranspiration among forest types. Secondly, this study did not apply paired watershed experiment to evaluate effect of deforestation on hydrological responses of forest. All selected forest types are located in a small catchment, indicating that the variability of soil water retention may be caused by other factors, not forest. In fact, beside soil moisture, soil depth and bulk density have strong influences on soil water retention (Table 5). Similarly to other place, deforestation in associate with soil degradation causes variation in soil water storage capacity among forest in the study area.

Deforestation usually leads to a reduction in canopy and ground cover (Table 1), causing adverse changes in soil properties such as bulk density, infiltration rate, water storage capacity (Lal, 1996) [10]. In Vietnam, the positive hydrological roles of canopies, vegetation – litter ground covering were proved by few studies. For example, rainfall interception loss by forest canopies is 10-20% in pine forest (Quynh, 1996) [20], 2.91-18.55% in both natural forest and plantation (Dien, 2006) [26]. An integrated index from canopy, vegetation ground cover, and dried litter cover was used as a criterion to evaluate the forest soil water storage capacity (Quynh, 1996) [20]. By comparing Table 1 and 5, a general conclusion can be made that deforestation in Thuong Tien in associated with soil degradation significantly causes a reduction in forest soil water retention (moderate forest's vs. grass+shrub's). An important finding is that soil moisture and soil water retention of poor forest and rehabilitation forest are approximately equal. As indicated above, rehabilitation forest was regenerated from grass+shrub, meaning that reforestation from degraded land can improve soil water retention capacity (rehabilitation forest's vs. grass+shrub's), more detail discussed by Bruijnzeel (1989) [27] and Scott et al. (2005) [21].

5. Conclusions

In this study, forest soil moisture of 40 forest plots of four forest types (moderate forest; poor forest; rehabilitation forest; grass + shrub) were analyzed in relation to the environmental factors, including forest structures, rainfall, porosity, soil depth, and slope. The results from this study give some scientific evidences that the effects of forest degradation on forest soil moisture are clear.

The variation of forest's structure and soil porosity has resulted in a variation of soil moisture among forest types. Measured data show that average topsoil moisture always decreases, in turn, from moderate forest to poor forest, rehabilitation forest, and mixed grass + shrub.

There is a strong multi-linear relationship between forest soil moisture and environmental factors for selected forest types (R^2 = 0.64 –

0.83). The most important factors affecting forest soil moisture are litter cover, ground cover, and porosity. These independent variables are at least significant in three of four regression equations for four forest types.

Forest soil moisture can be predicted by two models: (1) prediction model for a rainy day; (2) prediction model for a no rainy day. The determination coefficients (R^2) of the two models are 0.55 – 0.81, and 0.52 – 0.83, respectively. Rainfall and antecedent soil moisture are the two main predictors affecting the first model. Those of model 2 are time interval (days) and soil moisture of a rainy day (predicted by model 1). Forest's structure and soil porosity are positive relation to soil moisture prediction, whereas, slope (model 1) and time (model 2) are inversely proportional to soil moisture prediction. Models for moderate forest are validated by 70 independent soil samples (RSME = 2.03%).

Forest soil water retention also varies among forest types. The highest capability to retain water in soil is in moderate forest (401mm) and the lowest one is in grass + shrub (249mm). Those of poor forest and rehabilitation forest are approximately similar (350mm). At monthly time scale, there is a same trend of soil moisture among forests. Annually, the highest water storage capacity in the soil is in August, and the lowest one in February, meaning that these months can store more or less rainy water than the others.

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