THE CORRELATION ANALYSIS BETWEEN SWAT PREDICTED SOIL MOISTURE AND MODIS NDVI

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ABSTRACT: The purpose of this study is to identify how much the MODIS NDVI (Normalized Difference Vegetation Index) can explain the soil moisture simulated from SWAT (Soil and Water Assessment Tool) continuous hydrological model. For the application, ChungjuDam watershed (6,661.3 km^2) was adopted which covers land uses of 82.2 % forest, 10.3 % paddy field, and 1.8 % upland crop respectively. For the preparation of spatial soil moisture distribution, the SWAT model was calibrated and verified at two locations (watershed outlet and Yeongwol water level gauging station) of the watershed using daily streamflow data of 7 years (2000-2006). The average Nash and Sutcliffe model efficiencies for the verification at two locations were 0.83 and 0.91 respectively. The 16 days spatial correlation between MODIS NDVI and SWAT soil moisture were evaluated especially during the NDVI increasing periods for forest areas.

KEY WORDS: SWAT, Soil Moisture, MODIS NDVI, HRU, Land Use

1. INTRODUCTION

Streamflow is often used for calibrating hydrologic model, SWAT (Soil and Water Assessment Tool). However, streamflow account for a smaller fraction of the hydrologic component than evapotranspiration and soil moisture (Narasimhan et al., 2005).

Soil moisture is the important hydrologic component of water balance, and it would be ideal to use soil moisture for model calibration if the measured data are available at the study area. However usually due to the lack of measured soil moisture data, we need a pseudo indicator of soil moisture condition. The monitoring and modelling of land surface and vegetation processes by using satellite images viz. NOAA AVHRR or Terra MODIS is now popular for the assessment of hydrologic behavior. Farrar et al. (1994) found that NDVI and soil moisture are well correlated in the plant growing periods. Hence, NDVI can be a useful indicator to analyze the soil moisture during the active growing of crop or plant, and to determine the soil moisture condition for drought monitoring (Narasimhan et al., 2005).

So, this study tried to analyze the correlation between the SWAT simulated soil moisture and MODIS NDVI for the soil moisture indicator.

2. MATERIAL AND METHOD

2.1 Study Watershed

A 6,661.3 km^2 watershed (ChungjuDam) was adopted (Figure 1). It lies between 127°53'49"E - 128°55' E and 37°18'28"N - 37°47'3"N. Forest area covers about 83%. The annual precipitation is 1,198mm during the past 30 years.

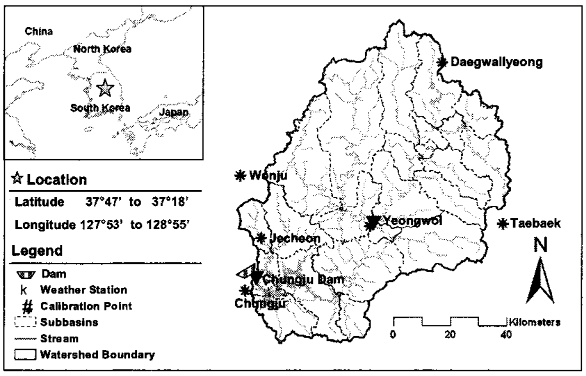
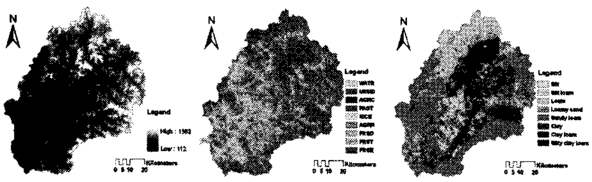


Figure 1. Study Area.

2.2 SWAT Model Description and Input Data

SWAT is a physically based basin-scale, continuous time, distributed parameter hydrologic model that uses spatially distributed data on soil, land use, Digital Elevation Model (DEM), and weather data for hydrologic modeling and operates on a daily time step (Narasimhan, 2005). Weather inputs needed by SWAT are precipitation, maximum and minimum air temperatures, wind velocity, relative humidity, and solar radiation (Narasimhan et al., 2005). For this study, 7 years (2000-2006) daily precipitation measured at 35 automatic weather stations (AWS) and other weather data measured at 6 weather stations were obtained from Korea Meteorological Administration.

As the spatial data for SWAT model, elevation data were rasterized as 30 m DEM from a 1:5,000 vector map that was supplied by the Korea National Geography Institute (Figure 2a). The 30 m land use data were prepared by classifying the Landsat TM (Thematic Mapper) satellite image of 2000, and reclassified the forest to evergreen, deciduous, and mixed forests using 2000 NOAA NDVI data (Figure 2b). Soil database and the attributes for the model were obtained from the Korea Rural Development Administration (Figure 2c). The watershed was divided into 25 subbasins. The subbasin is subdivided into 376 HRU (Hydrological Response Unit). SWAT model create input parameter and perform simulation, through HRU.



(a) DEM (b) Land use (c) Soil

Figure 2. GIS data.

2.3 Soil Moisture Routing in the Model

The SWAT model runs on a daily time-step. The hydrological component is based on the water balance equation.

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - \varpi_{seep} - E_a - Q_{gw})$$

where SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), w_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of returnflow on day i (mm H_2O).

2.4 Terra MODIS NDVI

In this study, the MODIS NDVIs of 250 m spatial resolution and 16 days temporal resolution were obtained from website for 7 years (2000-2006).

3. RESULTS AND DISCUSSION

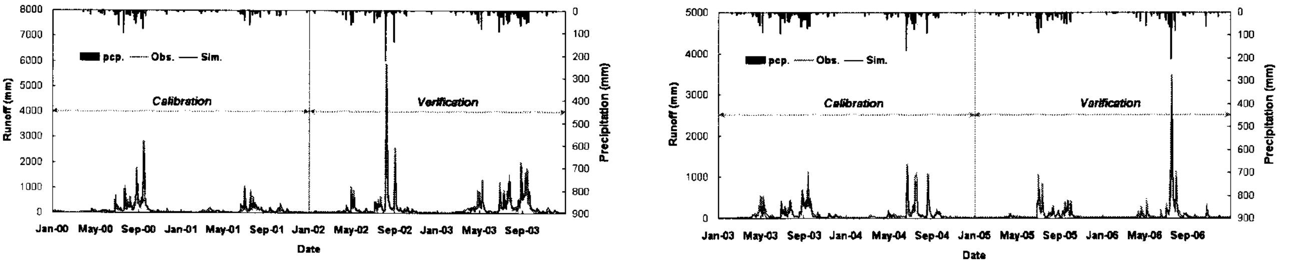
3.1 Model Calibration and Verification

The model was calibrated at two locations (ChungjuDam and Yeongwol) using the streamflow data. Multisite calibration enhances the calibration results with the viewpoint of spatial variation. ChungjuDam is watershed outlet and Yeongwol covers 4,172.9 km^2 of the watershed. ChungjuDam was calibrated using 4 years (2000-2003) data and Yeongwol was calibrated using 4 years (2003-2006) respectively. The calibrated model parameters are shown in Table 1.

Table 2 and Table 3 summarize the statistics of model calibration and verification respectively, and Figure 3 shows the comparison of observed and simulated streamflows of the two locations. The determination of coefficients (R^2) and the Nash-Shutcliffe model efficiencies were 0.84 and 0.79 at ChungjuDam, and 0.90 and 0.91 at Yeongwol respectively.

Table 1. The calibrated model parameters

Parameter	Description	Calibration Range	Chungju Dam Optimal value	Yeongwol Optimal value
CN2	Curve number adjustment ratio	± 20 %	-8	8
ESCO	Soil evaporation compensation	± 20 %	0.1	0.1
CANMX	Maximum canopy storage (H_2O)	0~100	20	20
SOL_AWC	Available water capacity	± 20 %	0.025	0.025
SFTMP	Snowfall temperature (℃)	-5 ~ 5	0	0
SMTMP	Snowmelt base temperature (℃)	-5 ~ 5	0	0
SMFMX	Maximum snow melt factor (mm H_2O/°C-day)	0 ~ 10	6	6
SMFMN	Minimum snow melt factor (mm H_2O/°C-day)	0 ~ 10	2	2
TIMP	Snow pack temperature lag factor	0 ~ 1	0.5	0.5
SNOCOVMX	Minimum snow water content that corresponds to 100 % snow cover	0 ~ 500	50	50
LAT_TTIME	Lateral flow travel time (days)	-	0	3
GW_DELAY	Groundwater delay time (days)	0 ~ 500	120	150
CH_K2	Effective hydraulic conductivity of main channel	0 ~ 50	30	60



(a) ChungjuDam (b) Yeongwol

Figure 3. Comparison of observed versus simulated streamflow at two locations.

Table 2. The Calibration and Verification statistics at ChungjuDam Observation Station

Period	Year	Rainfall (mm)	Runoff (mm)		Runoff Ratio (%)		R^2	RMSE	ME
			Obs.	Sim.	Obs.	Sim.			
Calibration	2000	1170.5	608.4	664.9	52.0	56.8	0.86	1.50	1.00
	2001	811.0	310.6	399.4	38.3	49.3	0.73	1.03	0.38
Verification	2002	1454.6	840.6	840.6	57.8	57.8	0.91	2.19	0.91
	2003	1688.1	1050.9	1050.8	62.3	62.3	0.84	1.68	0.85
Mean		1281.1	702.6	738.9	52.6	56.6	0.84	1.60	0.79

Table 3. Calibration and Verification statistics Yeong-wol Observation Station

Period	Year	Rainfall (mm)	Runoff (mm)		Runoff Ratio (%)		R^2	RMSE	ME
			Obs.	Sim.	Obs.	Sim.			
Calibration	2003	1733.2	756.1	653.8	43.6	37.7	0.88	1.07	0.90
	2004	1466.4	642.2	556.5	43.8	38.0	0.93	1.02	0.93
Verification	2005	1305.3	498.8	414.0	38.2	31.7	0.85	0.98	0.86
	2006	1613.6	790.4	614.4	49.0	38.1	0.94	1.59	0.94
Mean		1529.6	671.9	559.7	43.7	36.4	0.90	1.17	0.91

3.2 The Correlation Analysis between SWAT Soil Moisture and MODIS NDVI

The SWAT simulated soil moisture was analyzed with the MODIS NDVIs by HRU. The analysing periods are the active phase of leaf growing season from March to June of 7 years (2000 – 2006). The correlations between forest NDVI and SWAT soil moisture are shown in Table 4, and Figure 4 shows the scatter plots. As the regression equations in Table 4 and from the slope in Figure 4 between NDVI and soil moisture, the two variables are in an inverse proportion.

During the leaf growing period, plants need soil water for transpiration. Evaporation from surface also increases because temperature rises from March to June. Thus the soil moisture is forced to decrease while NDVI increases by the leaf growth. Meanwhile, the soil moisture varies with rainfall. Soil moisture increases by rainfall and decreases before the next rainfall. Thus the fluctuation of soil moisture by rainfalls affects the relation with NDVI because the NDVI continuously increases during the growing period even promoting the growth via rainfalls. The determination of coefficient among the 7 years showed the highest value during 2001 growing season with bigger inverse slope value than that of other years. The 2001 from March to 20th of June suffered a severe drought. The rainfalls were just 25 % of a normal year. Thus the continual decrease of soil moisture which was not interrupted by rainfalls during the period showed a more reverse relationship between the two variables. The low correlation of 2002 came from the frequent rainfalls.

Table 4. The correlation between forest soil moisture and MODIS NDVI

year	Rainfall (mm)	Equation (y = Soil Moisture, x = NDVI)			R^2		
		Deciduous	Evergreen	Mixed	Deciduous	Evergreen	Mixed
2000	1183.6	y = -2.8054x + 16.84	y = -2.7249x + 15.629	y = -2.4605x + 15.732	0.57	0.70	0.59
2001	834.3	y = -10.114x + 22.183	y = -11.543x + 21.031	y = -10.188x + 21.362	0.87	0.81	0.84
2002	1450.3	y = 0.5036x + 15.138	y = -0.3726x + 14.072	y = -0.5838x + 14.903	0.02	0.01	0.03
2003	1693.7	y = -4.8587x + 20.618	y = -5.1492x + 19.28	y = -3.8745x + 17.463	0.57	0.67	0.67
2004	1476.1	y = -2.7942x + 17.591	y = -3.8549x + 16.533	y = -4.8926x + 19.759	0.54	0.54	0.59
2005	1339.5	y = -3.8983x + 18.14	y = -4.6884x + 16.732	y = -5.252x + 17.898	0.66	0.55	0.66
2006	1616.0	y = -2.8528x + 18.305	y = -3.1239x + 15.915	y = -3.8745x + 17.463	0.42	0.58	0.53
Total	1370.5	y = -3.8417x + 18.421	y = -4.7821x + 17.977	y = -4.3157x + 16.971	0.52	0.55	0.56

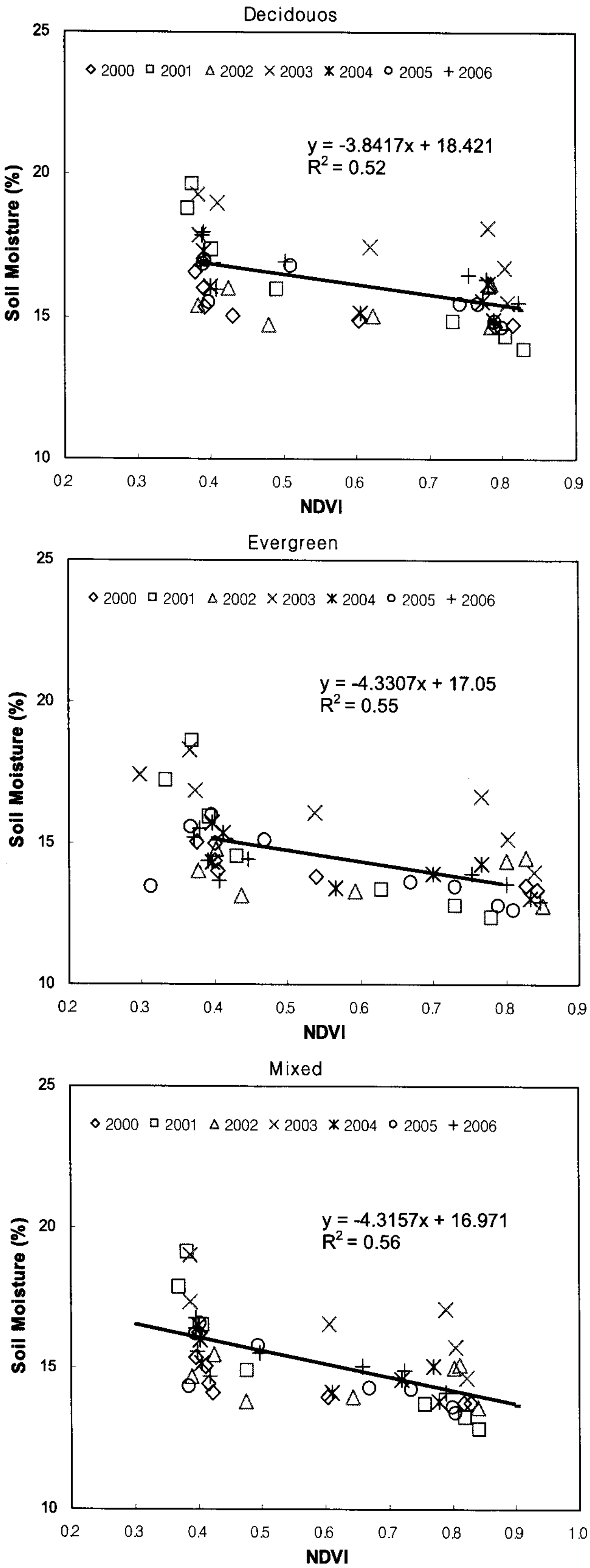


Figure 4. The Correlation between forest soil moisture and MODIS NDVI in growing season for 7 years.

4. CONCLUSIONS

This study analyzed the correlation between SWAT simulated soil moisture and MODIS NDVI during leaf growing period. By analyzing the 7 years (2000 - 2006) data from March to June, the NDVI and soil moisture showed an inverse proportion. Especially, the relationship between the two variables was the best for drought case with the determination of coefficient above 0.8 by the continual decrease of soil moisture without fluctuation and the NDVI increase during the period.

Thus, it can be possible to use the regression equation of drought growing period for estimating the soil moisture by using the MODIS NDVI.

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