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ARTICLE

Assessing the effect of watershed slopes on recharge/baseflow and soil erosion

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Abstract Aquatic ecosystems are threatened by increasing variability in the hydrologic responses. In particular, the health of river ecosystems in steeply sloping watersheds is aggravated due to soil erosion and stream depletion during dry periods. This study suggested and assessed a method to improve the adaptation ability of a river system in a steep watershed. For this, this study calibrated soil and water assessment tool (SWAT) for runoff and sediment, and quantified the changes in hydrologic responses such as groundwater recharge rate soil erosion and baseflow according to two scenarios for adjustment of the watershed slope (steep to mild). Here, one scenario was set by three measured slopes, and the other was set by fixing the entire watershed slopes with 5 %. Moreover, SWAT and web-based hydrograph analysis tool (WHAT) models were applied to estimate groundwater recharge, soil erosion, and baseflow in the Haean-myeon watershed in South Korea. The results show that the reduction of watershed slope increased groundwater recharge and baseflow, and decreased sediment. Specifically, groundwater recharge rate was increased from 257.10 to 364.60 mm, baseflow was increased from 0.86 to 1.19 m^3/s, and sediment was decreased from 194.6 to 58.1 kg/km^2. Based on these results, the suggested method will positively contribute to aquatic ecosystems and farming environments in a steeply sloping watershed due to improvements in the quantity and quality of river water.

Keywords Linked groundwater · Baseflow · Recharge · Sediment · Steep sloping watershed

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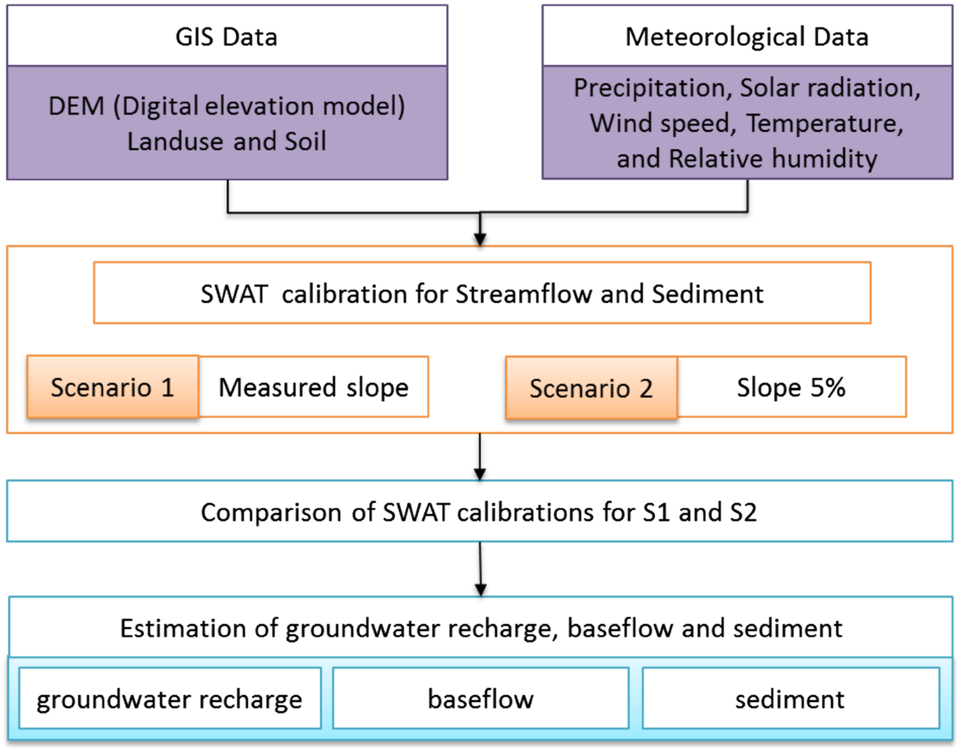
Introduction

Climate change has contributed significantly to variability in hydrologic responses over the world (Allen and Ingram 2002; Wu et al. 2014). Sequentially, more strong and frequent flood and drought have become more serious threats to human communities and ecosystems. With climate change, variability in hydrologic responses is differently propagated according to watershed characteristics such as topography, soil type, and land use (e.g., Adnan and Atkinson 2011; Ali et al. 2012; Yan et al. 2013; Bieger et al. 2014). Particularly, direct runoff in a steep sloping watershed is typically more sensitive to precipitation events than in a mild sloping watershed. Steepness of a watershed can produce negative effects such as stream depletion and soil erosion to aquatic ecosystems and agricultural activities. In this regard, assessing the effect of a

Fig. 1 Procedure



watershed slope on hydrologic responses is necessary to improve watershed managements including water and soil resources.

Understanding the characteristics of hydrologic responses in a watershed is necessary for efficient management of water resources since hydrologic responses are connected to each other (Brooks et al. 2012; He and Hogue 2012; Paul and Bayode 2012). For example, stable supply of baseflow into streamflow by increasing groundwater recharge in long-term perspectives will help improve aquatic ecosystems due to the reductions in direct runoff and soil erosion. However, the long-term monitoring needed to measure groundwater recharge, baseflow, and soil erosion in the field is difficult to support in terms of personnel and financing. To overcome this difficulty, various computer models corresponding to changes in boundary conditions have been developed and applied to the estimation of hydrologic responses (Zhang et al. 2007; Luo et al. 2012). Many models are available to estimate recharge/baseflow or soil loss: MOHISE (Brouyre et al. 2004), MODFLOW (modular three dimensional finite difference ground water flow; McDonald and Harbaugh 1988), DRAINMOD (drainage and related water management system; Skaggs 1982), HELP (hydrologic evaluation of landfill performance; Schroeder et al. 1994), SWAT (soil and water assessment tool; Arnold et al. 1998), SATEEC (sediment assessment tool for effective erosion control; Lim et al. 2003; Park et al. 2010), and WEPP (water erosion prediction project; Flanagan and Livingston 1995).

Among the previously mentioned models, the SWAT model has been widely used in many environmental, hydrological applications over the world (e.g., Ficklin et al. 2013; Guse et al. 2014). SWAT can quantify the changes in hydrologic responses such as runoff, water quality, groundwater recharge, and soil erosion in a watershed for various scenarios (Ryu et al. 2010). For this reason, SWAT has been applied to many simulations for water resources management around the world. In this regard, many SWAT applications have been used to assess the effects of the DEM resolutions, land cover change, and climate change on direct runoff/recharge and soil erosion in SWAT modeling (e.g., Chaubey et al. 2005; Li et al. 2009; Ghaffari et al. 2010). These advantages support the suitability of SWAT in assessing the effect of watershed slopes on groundwater recharge, runoff, and soil erosion in a watershed.

Baseflow estimations can be typically conducted by methods to separate baseflow from the observed streamflow in gauged watersheds. For ungaged watersheds, baseflow can be estimated directly by numerical models or separated indirectly from the predicted streamflow using rainfall-runoff models such as SWAT and HSPF. In baseflow estimation using numerical models, calibration of the models is typically performed for the observed streamflow due to the lack of the observed baseflow data. Among

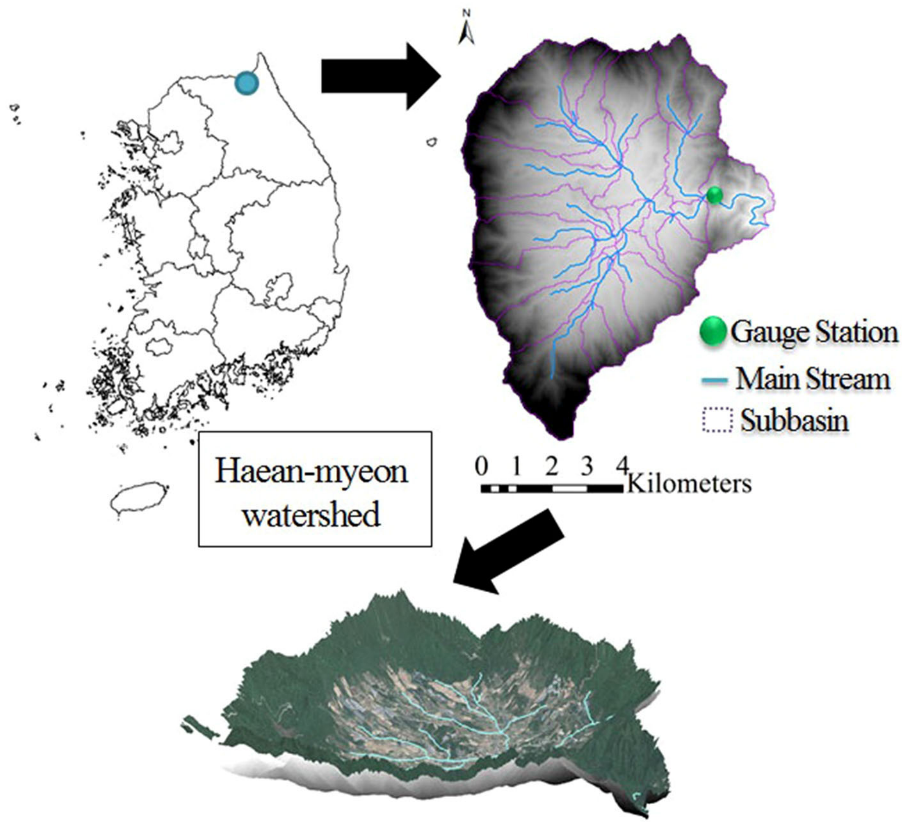


Fig. 2 Study area: punch bowl shaped Haean-myeon watershed

several hydrograph separation methods, the Eckhardt filter (Eckhardt 2005) in the web-based hydrograph analysis tool (WHAT) system (Lim et al. 2005) has an advantage of separating direct runoff and baseflow from hydrograph by using the BFI_{max} parameter reflecting the characteristics of individual aquifer, compared to the digital filter (Lyne and Hollick 1979; Nathan and McMahon 1990; Arnold and Allen 1999; Arnold et al. 2000). BFI_{max} values proposed by Eckhardt (2005) are 0.80 for perennial streams with porous aquifers, 0.50 for ephemeral streams with porous aquifers, and 0.25 for perennial streams with hard rock aquifers. However, Eckhardt (2008) suggested calibrations of BFI_{max} by using tracer data.

To assess the effect of watershed slopes on hydrologic responses, this study attempted (1) to calibrate the SWAT model for runoff and sediment in a steep sloping watershed; (2) to estimate groundwater recharge, soil erosion, and baseflow for two scenarios on watershed slopes. To achieve these objectives, the SWAT model was applied to estimate the field-based groundwater recharge and soil erosion and runoff at an outlet of a watershed for two scenarios on watershed slope: (1) field surveyed slope and (2) the fixed slope of 5 % (from steep to mild). Moreover, separation of the baseflow from streamflow was performed with the WHAT system. Information from this study will contribute significantly to the watershed management for sustainable stream functions based on the low impact development in the steep sloping watershed which is exposed to a relatively high risk of stream depletion and soil erosion. Procedure of this study is shown in Fig. 1.

Materials and methods

Study area

The study area is a watershed of 63.08 km^2 located in Haean-myeon, Yanggu-gun, Gangwon-do, Republic of Korea. The watershed is surrounded by high mountains over 1,000 m, and it is geologically different from other places in Yanggu-gun. The streams in the watershed of Haean-myeon are mainly dominated by direct runoff and join the Mandea stream, a main stream in the watershed. The Mandea stream is a tributary of Soyang River which is a part of Han River. In the selected watershed, land use distribution is consisted of forest (54.70 %), agriculture (30.52 %), grassland (9.85 %), residential and urban area (4.88 %), and water (0.05 %).

Table 1 Summary of climate data

Data type	Source	Periods	Application
Precipitation	KMA	Jan. 2007–Dec. 2009	Warming-up in calibration
		Sep. 2010–Dec. 2010	Prediction
	TERRECO	Jan. 2010–Aug. 2010	Calibration/ prediction
Temperature	KMA	Jan. 2007–Dec. 2009	Warming-up in calibration
		Sep. 2010–Dec. 2010	Prediction
	TERRECO	Jan. 2010–Aug. 2010	Calibration/ prediction
Wind speed	KMA	Jan. 2007–Dec. 2009	Warming-up in calibration
		Sep. 2010–Dec. 2010	Prediction
	TERRECO	Jan. 2010–Aug. 2010	Calibration/ prediction
Solar radiation	KMA	Jan. 2007–Dec. 2009	Warming-up in calibration
		Sep. 2010–Dec. 2010	Prediction
	TERRECO	Jan. 2010–Aug. 2010	Calibration/ prediction
Humidity	KMA	Jan. 2007–Dec. 2009	Warming-up in calibration
		Sep. 2010–Dec. 2010	Prediction
	TERRECO	Jan. 2010–Aug. 2010	Calibration/ prediction

The Haean-myeon watershed has a geometric shape of an ellipse and geological depression consisting of a central cavity, prompting the name "Punch Bowl." The watershed has the elevation distribution range from 400 to 1,304 m, and the U-shaped cross-sections. Moreover, the average slope of the river in the watershed is about 11°, and the river slope is gradually decreased from upstream (20°) to downstream (5°) (Fig. 2). In spite of the steep riverbed slope, the watershed has been used as an alpine agriculture region, which needs soil reconditioning and fertilizer use. Since rainfall leads to inflow of sediment and nutrients into the water body, the selected watershed is recognized as an origin of non-point pollution and sediment in the stream. This watershed was selected as a study area due to its unique geological characteristics that negatively affect the aquatic ecosystem owing to river depletion and contaminated sediments by decreasing baseflow and increasing direct runoff (Bartsch et al. 2013; Shope et al. 2013).

SWAT model description

SWAT is a semi-distribution rainfall-runoff model developed by the United States Department of Agriculture/ Agriculture Research Service (USDA/ARS) (Arnold 1992; Arnold et al. 1998). The SWAT model can be used to simulate long-term rainfall-runoff and to predict sediment transport and processes. Simulations of runoff, sediment, and nutrient loads are also possible in ungaged watersheds (Arnold et al. 1998). In particular, the SWAT model can quantitatively estimate the changes in water quality due to changes in land use, climate, and vegetation. Typically, SWAT needs climatic data, land use and soil distribution, topographic data, and agricultural management data (Arnold 1992; Arnold et al. 1998). The SWAT model performs the simulations based on the HRU (hydrological response unit) concept which uses a combination of land use, soil, and watershed slope. However, application of SWAT to a steeply sloping watershed is affected by watershed subdivision in simulating accurate runoff and sediment since the SWAT model uses the relationship between the average slopes and the average slope lengths in sub-watersheds for estimating slope length of HRU (Kim et al. 2009). Accordingly, this study used the SWAT model by considering the topographic characteristics (e.g., slope) of HRUs in each sub-watershed in order to estimate accurate runoff and sediment transport in the study area.

Meteorological and topographical data

Climatic data used in the SWAT model are daily radiation (MJ/m), daily precipitation (mm), daily mean relative humidity (%), daily mean wind velocity (m/s), and daily maximum/minimum temperature (°C) from January 2007 to December 2010 at 11 gage stations provided by TERRECO (terrain and ecological heterogeneity) and KMA (Korea Meteorological Administration). Table 1 shows the climate data used in this study. With TERRECO data, KMA data are used for warming-up and prediction because TERRECO data used in this study are available only from Jan. 2010 to Aug. 2010. Figure 3a and b shows the locations and the annual precipitation amount of 11 gage stations in the Haean-myeon watershed (Lee et al. 2011). Annual precipitation amount shown in Fig. 3b was weighted from 11 gage stations. Precipitation, a major contributor to runoff and groundwater recharge, shows a large deviation for 11 gage stations. In 2010, W8 recorded the greatest annual precipitation of 1,504 mm and W11 recorded the least annual precipitation of 1,100 mm. Precipitation in the study watershed shows spatially and temporally different pattern in magnitude and frequency of precipitation (Shope et al. 2013).

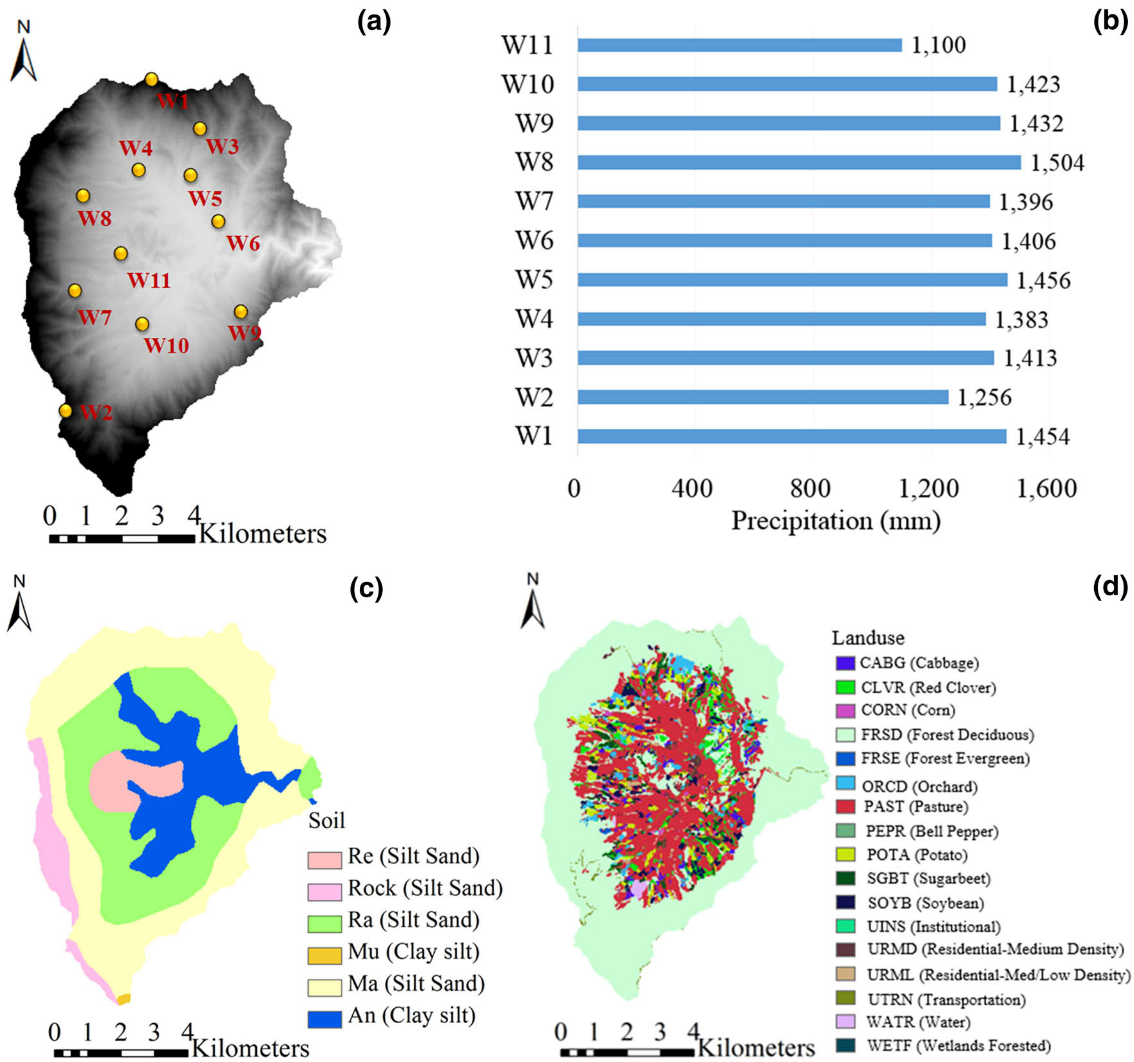


Fig. 3 SWAT input. **a** Location of weather stations in Haean-myeon watershed, **b** precipitation at 11 weather stations, **c** major soil types in the Haean-myeon watershed, and **d** land use in the Haean-myeon watershed

In this study, a DEM (digital elevation model) was constructed by using digital GIS maps (1:5,000) provided by the National Geographic Information Institute, Republic of Korea; and the reconnaissance soil map (1:50,000) provided by the Rural Development Administration (RDA), Republic of Korea, was used as a base soil map. Soil types in Haean-myeon watershed mainly consist of Re (Silt–Sand), Rock (Silt–Sand), Ra (Silt–Sand), Mu (Clay–Slit), Ma (Silt–Sand), and An (Clay–Slit) (Fig. 3c). In SWAT simulations, if the accuracy of the land use map is low, the results will be underestimated or overestimated because the curve number method in SWAT relates runoff to the combination of soil type and land use (Heo et al. 2008). Accordingly, this study constructed the detailed land use maps including the crop map compiled by the TERRECO research team in order to predict accurately the streamflow and groundwater recharge in the Haean-myeon watershed (Fig. 3d). In this regard, the detailed methodology of combining the soil map, test pits and the land use to derive spatially variable soil property was described in a previous study (Shope et al. 2013). Agricultural information, such as cultivation method, tillage, and fertilization, for seven main crops, obtained from TERRECO, was used as input data in SWAT. Such information is manipulated based on the crop management manual provided by the RDA and constructed as a database applicable to the SWAT model (Table 2).

Watershed slope in SWAT applications

SWAT is made up of the implicit process-based equations using empirical data. In SWAT applications, the watershed scale can influence the accuracy of the predicted results because the SWAT parameters depend on the

Table 2 Scenarios of crop cultivation periods in SWAT crop management

Crop	Plant/begin growing season	Fertilizer applications	Pesticide applications	Tillage	Irrigation	Harvest and kill
Rice	May 20	Jan. 5	Jun. 1	Jan. 5	Mar. 1	Oct. 15
		Aug. 1		Mar. 1	May 17	
		(auto fertilizer)		Nov. 1	(auto irrigation)	
Corn	May 1	–	May 5	Jun. 1	Jun. 1	Aug. 15
Soybean	May 1	–	May 5	Jun. 1	Aug. 15	Nov. 1
Radish	Mar. 1	May 7	Mar. 7	Mar. 10	Mar. 10	May 5
		(auto fertilizer)				
Potato	Mar. 15	Feb. 2	Apr. 7	Feb. 1	–	Jul. 7
	Aug. 10	Jul. 11	Aug. 20	Apr. 7		Oct. 20
			Sep. 18	Jul. 10		
				Aug. 25		
Cabbage	Mar. 1	Mar. 7	Mar. 7	–	Mar. 7	May 5
	Jul. 10	Aug. 5	Aug. 5		(auto irrigation)	Oct. 20
Pepper	May 1	May 5	May 5	Jun. 1	Aug. 15	Nov. 1

characteristics sub-watershed such as land use, climate, soil, and topography. A theoretical description of SWAT to estimate hydrologic responses is available at Arnold et al. (1998). In this regard, the impact of sub-watershed scale can lead to increased uncertainty in predictions of the hydrologic responses, soil erosion, and non-point pollution using the SWAT model to the study of watershed in Republic of Korea due to steep topographic conditions. Such differences in the topographic slope can bring errors, which occur in extracting other topographic factors using SWAT. In particular, the SWAT model estimates the mean slope length of sub-watershed by using the relationship between the mean slope of the sub-watershed and the slope length of the HRUs. In such a process, the sub-watersheds with all 25 % slopes or higher have 0.05 m HRU, which is not a physically meaningful number (Yoo et al. 2008). This limitation can bring errors in computing individual hydrologic components. Accordingly, this study attempted to simulate the accurate groundwater recharge and soil erosion by using the slope observed by TERRECO, where the measured slope is available for only central area of the Haean-myeon watershed (Fig. 4a, b). In this regard, this study assessed the effect of the slope in the central area of the Haean-myeon watershed on hydrologic responses in the entire watershed including the fringe area without the measured slope. Here, the slope in the fringe (steeper) area where the measured slopes are unavailable was calculated by SWAT, and then, combined with the measured slope of the area. Moreover, applications of the individual HRUs to the slope of sub-watersheds contribute to the reduction of errors arising from the SWAT calculation processes that sub-watersheds with all the 25 % slopes or higher have 0.05 m HRUs in predicting direct runoff, groundwater recharge, and soil erosion in Haean-myeon watershed, a typical steep sloped agricultural region (Fig. 4c).

Calibration of SWAT for runoff and sediment

In this study, the SWAT model was calibrated for streamflow and sediment. In the calibration process for sediment, the changed parameters can affect the estimation of runoff. For this reason, calibration of the model was concurrently performed for streamflow and sediment. Lee et al. (2013) showed that Surlag, LAT_Time, USLE_C, ALPHA_BF, and SLSOIL among the parameters involved in the SWAT model are most sensitive to the streamflow and sediment at the Haean-myeon watershed. In this regard, only five parameters in this study were calibrated for streamflow of 25 rainfall-runoff events from January 2010 to August 2010, and for sediment data of 20 rainfall-sediment events from January 2010 to July 2010, respectively. Here, the observed data were normalized by Eq. 1, while data outside ±95 % confidence intervals were excluded due to extreme values.

$$Z = \frac{x - \mu}{\sigma} \quad (1)$$

where Z is the normalized value, x is the value of observations, μ is the observation average, and σ is the standard deviation.

Calibration of the SWAT model was assessed by estimating determination coefficient and Nash–Sutcliffe

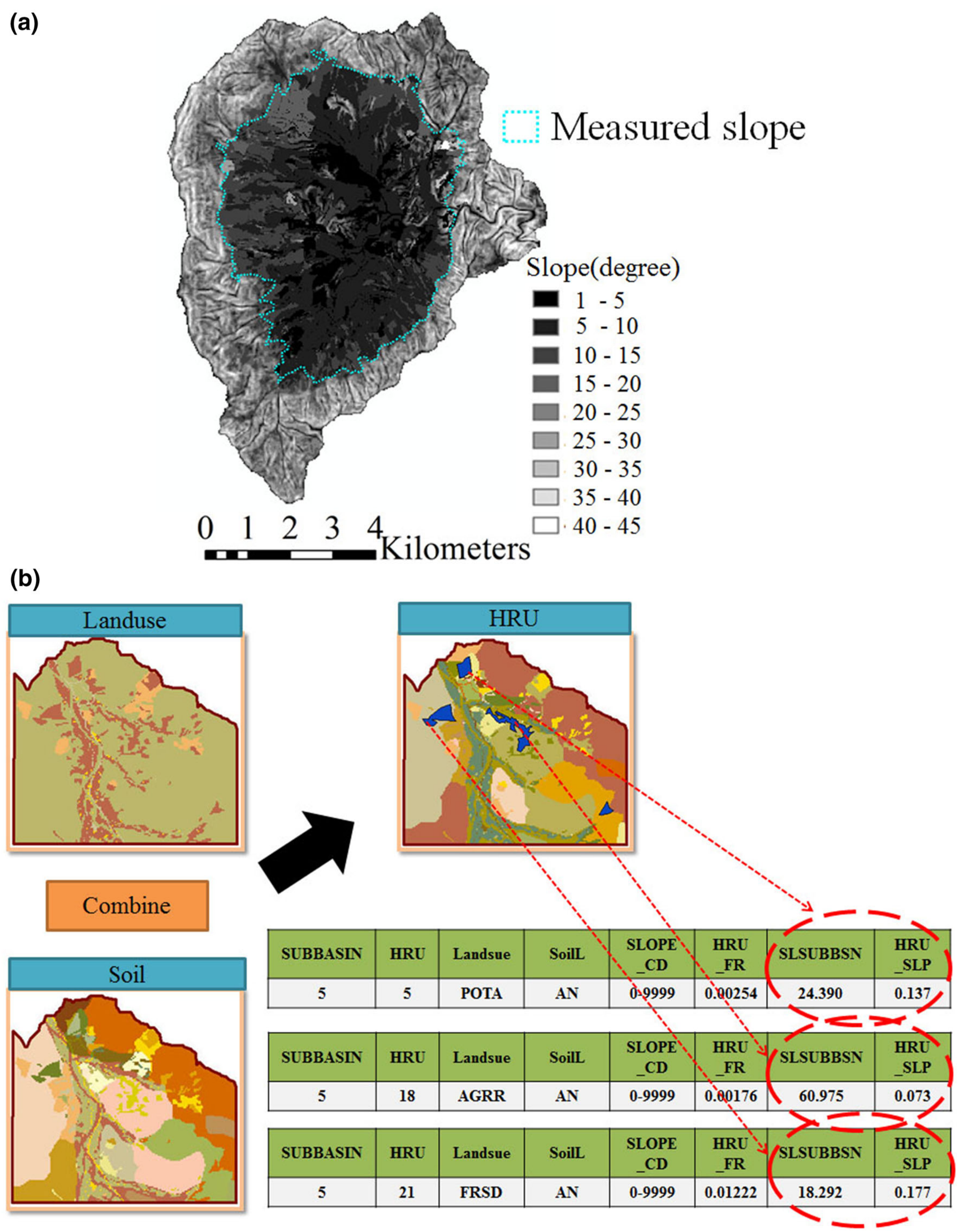


Fig. 4 The concept of application of the measured slope. **a** Slope in the Haean-myeon watershed and **b** measured slope to individual HRU in SWAT

efficiency (NSE) proposed by Nash and Sutcliffe (1970). NSE can be calculated by using Eq. 2.

$$\mathrm{NSE} = 1 - \left(\frac{\sum_{i=1}^{n} \left(y_{\mathrm{obs},i} - y_{\mathrm{sim},i} \right)^2}{\sum_{i=1}^{n} \left(y_{\mathrm{obs},i} - \overline{Y}_{\mathrm{obs}} \right)^2} \right) \quad (2)$$

where $y_{\mathrm{obs},i}$ is the ith observation, $y_{\mathrm{sim},i}$ is the ith simulation, $\overline{Y}_{\mathrm{obs}}$ is the mean of the observations, $\overline{Y}_{\mathrm{sim}}$ is the mean of the simulations, and n is the total number of observations.

Table 3 Nine parameters used in calibration for flow and SS estimation

Parameter	Description	Variation method	Value
CN2	USLE cropping and management (C) factor	Multiply by value	−23.125
SURLAG	Direct runoff lag time	Replace by value	0.075
LAT_TIME	Lateral flow travel time(days)	Replace by value	1.468
ALPHA_BF	Baseflow alpha factor	Replace by value	1.000
GW_DELAY	Groundwater delay	Add to value	9.918
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	Add to value	1.215
GW_REVAP	Groundwater “revap” coefficient	Add to value	0.050
SOL_AWC	Available water capacity of the soil layer	Multiply by value	−0.070
SOL_K	Saturated hydraulic conductivity	Multiply by value	0.200

High NSE value means good agreement between the observations and the simulations, and an NSE value of 1 indicates a perfect fitness. There are no standards for goodness-of-fit statistics to determine the acceptable performance (Busteed et al. 2009). However, R^2 (determination of coefficient) and NSE > 0.5 are typically considered acceptable (Ramanarayanan et al. 1997; Santhi et al. 2001; Van Liew et al. 2003).

Estimation of groundwater recharge and baseflow

In this study, spatio-temporal distributions of the monthly groundwater recharge for individual HRUs were analyzed using the predictions from the calibrated SWAT model for streamflow. Among groundwater recharge, the quantity of baseflow flowing into a river was also estimated by applying the streamflow predicted by SWAT to the WHAT system. Here, the SWAT model uses BFLOW filter for baseflow separation, but calibration was performed for streamflow and sediment, not baseflow. In this regard, if the calibration is acceptable by a certain threshold, streamflow predicted from the calibrated SWAT can be used for baseflow separation using the WHAT system in this study. The quantitative trends of baseflow and groundwater recharge in the Haean-myeon watershed were investigated from the ratio of baseflow to groundwater recharge and the ratio of groundwater recharge to rainfall.

Groundwater recharge, baseflow, and sediment according to change in slope angle of a watershed

The Haean-myeon watershed suffers from river depletion in the dry season and from soil erosion in the wet season. As a method to increase the quantities of groundwater recharge and baseflow to overcome this problem, this study changed the slope of agricultural land in the Haean-myeon watershed from steep to mild, and assessed its effect on the simulations using SWAT. For this, two different scenarios are prepared for the different slopes of agricultural land, and the results from SWAT simulations for two scenarios were compared, Here, one scenario is field surveyed slope, and the other scenario is fixed at 5 % (from steep to mild). The effect of change in slope angle of agricultural land on the estimation of streamflow, groundwater recharge, and sediment using SWAT was also analyzed by comparing two scenarios. Moreover, the effect of watershed slopes on baseflow was quantified by applying a baseflow separation method (WHAT) to the estimated streamflow using SWAT.

Results and discussion

Calibration of SWAT for runoff and sediment

Five most sensitive SWAT parameters affecting streamflow and sediment were calibrated to the observational data (Table 3). These parameters had first been calibrated for 25 observed daily streamflow data collected between January 2010 and August 2010, and then, calibrated again for 20 observed daily sediments collected between January 2010 and July 2010. The observed data were normalized to exclude data outside ±95 % confidence intervals due to extreme values. The calibration of the SWAT model for streamflow resulted in NSE 0.71 and R^2 0.80 (Fig. 5a). In particular, during the dry season, the simulated runoff reflects properties of the observation well. In a case of calibration for sediment, the estimated NSE and R^2 were 0.58 and 0.59, respectively (Fig. 5b). Given the threshold suggested by Ramanarayanan et al. (1997), the results of calibrations for streamflow and sediment showed good fitness between the simulations and the observations. However, the relatively low goodness of fit of the sediment calibration may be affected by the small number of observed data. Based on these results, it is expected that the calibrated SWAT model will well predict streamflow and sediment for the change in watershed slope in Haean-myeon watershed. However, calibration performed in this study has some limitations. The lack of observational data is a main limitation of this study because 25 data for streamflow and 20 data for sediment may be insufficient in

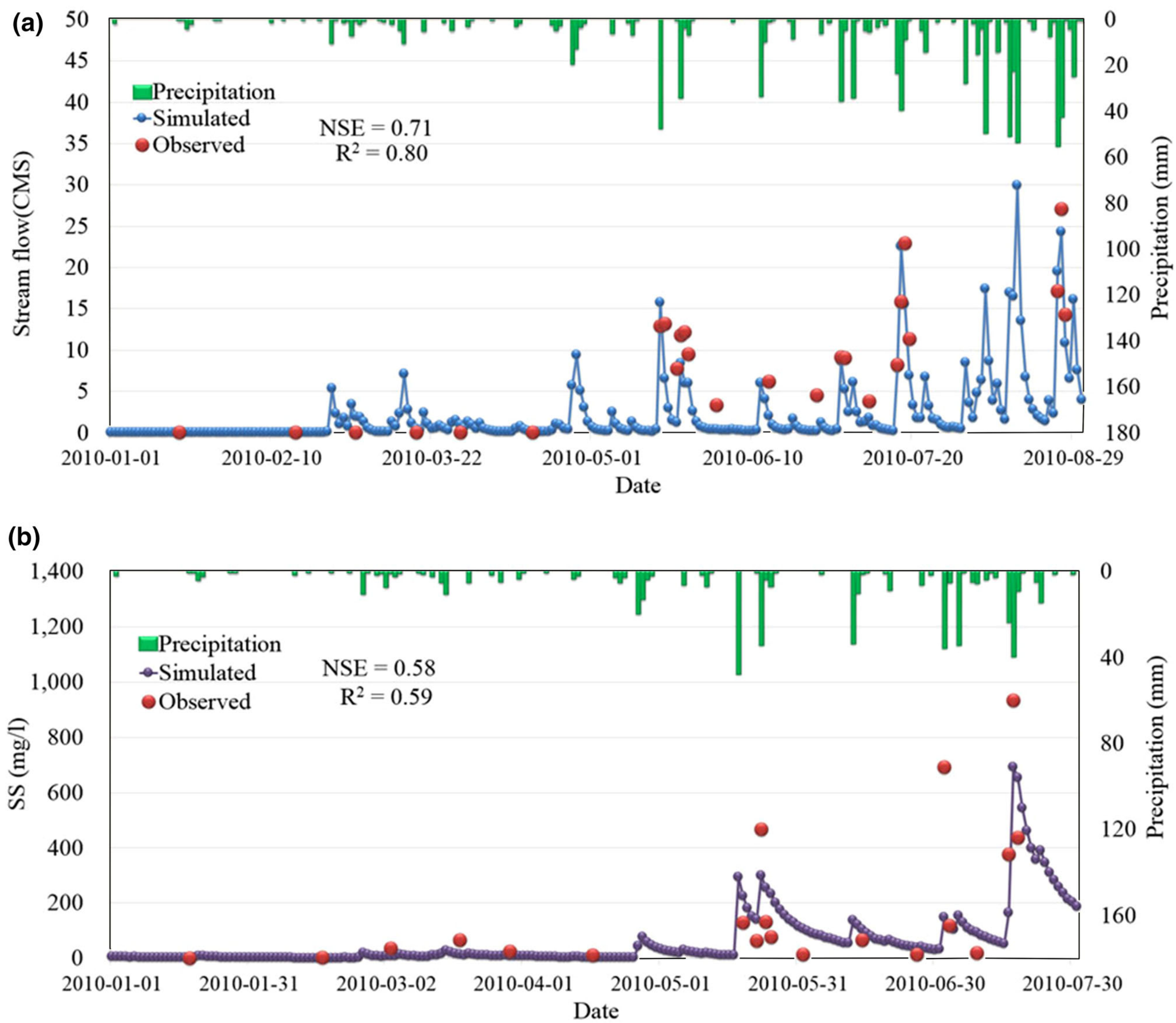


Fig. 5 Comparison of simulated and observed value. **a** SWAT calibration for flow comparison of simulated and observed and **b** SWAT calibration for SS comparison of simulated and observed

calibration of SWAT. Moreover, the calibration of only five parameters in SWAT is another limitation since other parameters can also affect calibration. In this regard, sufficiently observed data will improve calibration and validation of SWAT considering the effect of other parameters.

Monthly groundwater recharge

In this study, monthly groundwater recharge for individual HRUs was estimated by the calibrated SWAT model for the observed streamflow (Fig. 6). The estimated groundwater recharge in Haean-myeon watershed in 2010 was 251.7 mm/year with 1427.7 mm precipitation, and the ratio of groundwater recharge to precipitation was about 17.6 %. From the estimated monthly groundwater recharge, the September groundwater recharge (wet season) of 67.7 mm/month was 48 times greater than that of February groundwater recharge of 1.4 mm/month. October groundwater recharge is 130 % of precipitation but either side is <80 %. In this regard, the effect of precipitation in September seems to be propagated to groundwater recharge in October. Moreover, precipitation is less in September than August, but groundwater recharge is greater in September than in August. These results illustrated that it takes a long time for precipitation to reach groundwater recharge, and finally, the effect of precipitation in the last month is propagated to the groundwater recharge in the current month.

The estimated groundwater recharge in October was relatively large due to the high quantity of precipitation

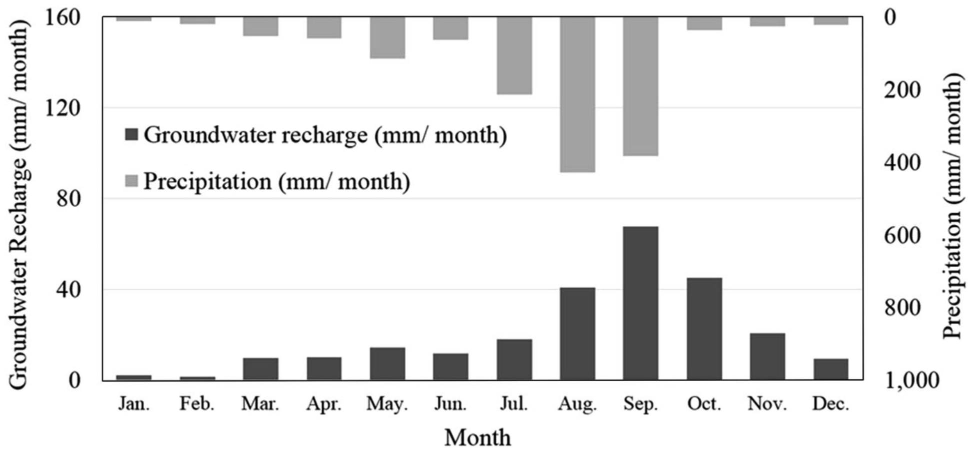


Fig. 6 Monthly precipitation vs. monthly groundwater recharge of the Haean-myeon watershed in 2010

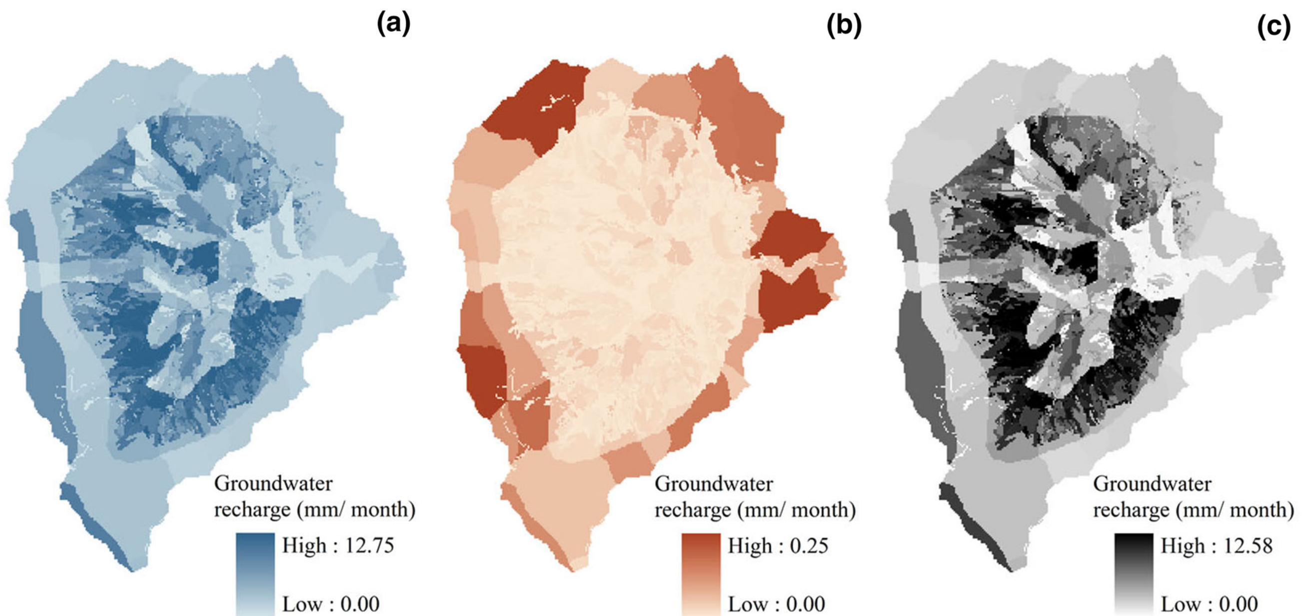


Fig. 7 Spatio-temporal distribution of monthly groundwater recharge of HRUs in 2010 (mm/month). **a** September (maximum), **b** February (minimum), and **c** difference between September and February

during the last 3-month period (Fig. 6). Figure 6 shows the temporal distributions in monthly groundwater recharge at the Haean-myeon watershed in 2010. Monthly groundwater recharge at the Haean-myeon watershed was the largest in September (wet season) and the smallest in February (dry season). This is possibly because the direct runoff in the marginal region flows into the central region with a mild slope due to the high precipitation in the wet season. Moreover, this can become another source of groundwater recharge or disastrous events like flood, sedimentation, and water pollution in the central region. Low and solid precipitation during the dry season can reduce groundwater recharge directly. In addition to low precipitation, snowpack or frozen soil layer in the dry season with low temperature can impact significantly the groundwater recharge (Jyrkama and Sykes 2007). However, analyzing the frozen soil layer is difficult because frozen soil is affected by several factors such as temperature, soil moisture, soil type, snow depth, and freezing duration (Daniel and Staricka 2000). Figure 7a and b shows the spatial distributions of monthly groundwater recharge of HRUs in September and in February. Spatial differences between the maximum (September) and the minimum (February) groundwater recharge of HRUs at the Haean-myeon watershed were high at fringe locations (steep slope) and low at central locations (mild slope) (Fig. 7c). However, spatial difference in groundwater recharge may be caused not only by slope, but also by land use and soil type; for example, the distribution of groundwater recharge by individual land use was largest

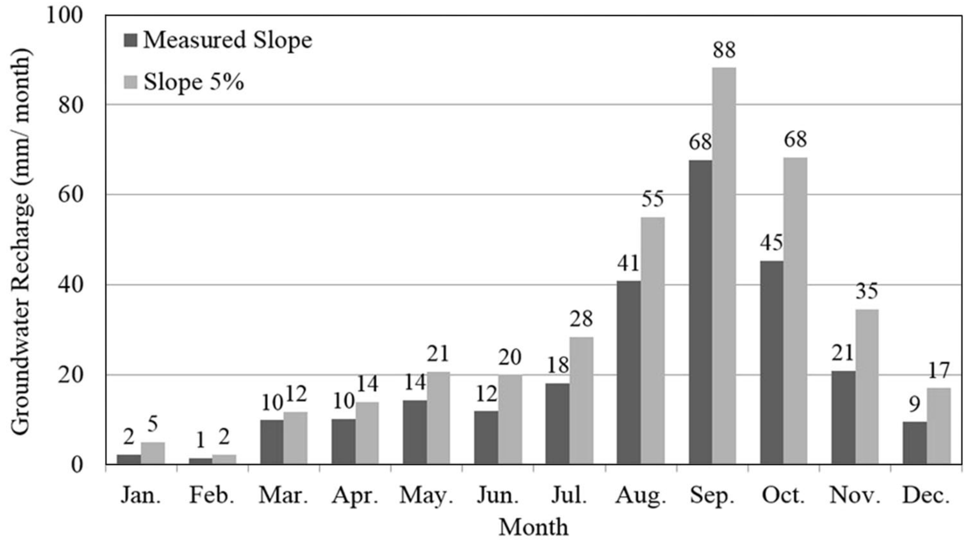


Fig. 8 Comparison of the estimated groundwater recharge for measured slope and slope 5 %

in forests and pastures, and relatively small in impervious areas.

Estimation of groundwater recharge and baseflow

In the Haean-myeon watershed in 2010, direct runoff against precipitation was 71.4 %, groundwater recharge against precipitation was 17.6 %, and baseflow against groundwater recharge was 4.6 %. However, this study conducted SWAT calibrations at one single point. The calibration results of this study were different from the results that Shope et al. (2013) who calibrated SWAT at multiple points. Such difference in calibration results of two studies can be propagated to predictions using SWAT. A major source of river in the Haean-myeon is direct runoff that flows from steep marginal region into central region with mild slope. The ratio of baseflow to precipitation calculated in this study was compared with previous results (Kim et al. 2011) of baseflow in relatively mild sloping watershed to identify its distinction in steep sloping watershed. The previous research (Kim et al. 2011) analyzed the ratios of baseflow to precipitation in mild sloping watersheds, such as Kyoungan-river watershed and Doam-dam watershed. Specifically, for each watershed, the ratios of area <10 % slope angle to the total area were 22 % for Kyoungan-river, 11 % for the Doam-dam, and 5.5 % for the Haean-myeon. Also, the ratios of baseflow to groundwater recharge were 40.3 % for the Kyoungan-river, 28.6 % for the Doam-dam, and 4.6 % for the Haean-myeon (Kim et al. 2011). Based on these results, the steeper sloping watershed leads to the smaller baseflow against groundwater recharge, and the groundwater recharge in mild sloping region was greater than in steep sloping region. Finally, greater groundwater recharge produced more baseflow.

Estimation of groundwater recharge, baseflow, and sediment according to change in slope angle of a watershed

As one way to increase groundwater recharge and to decrease sediment in a steep sloping watershed, this study evaluated the effect of reduction of field slope angle (measured slope) of the steep agricultural land in the entire area of the Haean-myeon, as a single catchment. The groundwater recharge estimated by reducing slope angle of the agricultural land was 364.60 mm, which was 42 % greater than by using the measured slope (257.10 mm) (Fig. 8). The effect of the reduced slope angle in a watershed also represented in a 38 % increase from 0.86 to 1.19 m^3/s in the estimated baseflow (Fig. 9a, b). Figure 9c and d shows a comparison of baseflow in May 2010 (dry season) and August 2010 (wet season) according to the slope angle of the watershed. Reducing the measured slope angle, the estimated streamflow in the Haean-myeon watershed increased from 0.4 to 0.56 m^3/s for May, and from 1.84 to 2.20 m^3/s for August. Contrary to streamflow, the estimated sediment decreased from 194.6 to 58.1 kg/km^2 (Fig. 10). This result is consistent with that of past studies which found significantly higher soil erosion on steep slope gradient than on mild slope gradient (e.g., Koulouri and Giourga 2007; El Kateb et al. 2013). From these results, it is expected that the reduction in the slope angle of the steep agricultural land located in the margin of the Haean-myeon watershed will increase the quantity of river water in dry season by increasing groundwater recharge and baseflow. In addition, water quality and ecosystem will be improved by reducing soil eroded in agricultural land and sediment flowing into the river. However, other factors affecting groundwater recharge, baseflow, and sediment should be considered with

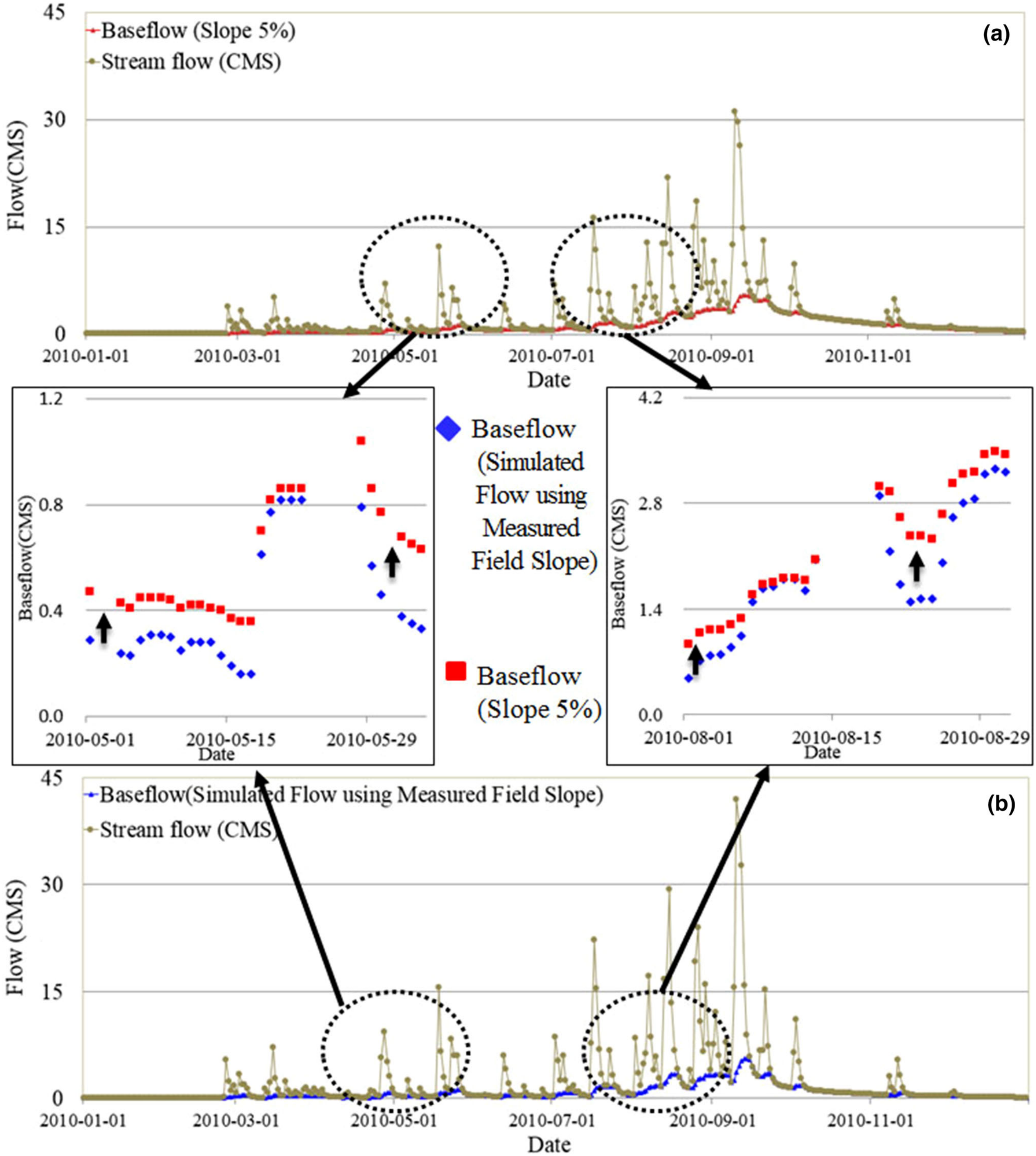


Fig. 9 Comparison of the estimated streamflow for measured slope and slope 5 % and comparison of baseflow using measured slope and slope 5 %. **a** Measured slope, **b** slope of 5 %, **c** baseflow using measured slope and slope 5 % (May), and **d** baseflow using measured slope and slope 5 % (August)

watershed slopes for reducing soil erosion and stream depletion. For example, land cover has a considerable impact on infiltration, surface runoff, and sheet erosion in mountainous regions (Zhang et al. 2004; Wei et al. 2007). Moreover, land slope reduction over steep agricultural land can be a tremendous amount of work and produce environmental conservation issues for the watershed. Accordingly, the land slope reduction should be determined

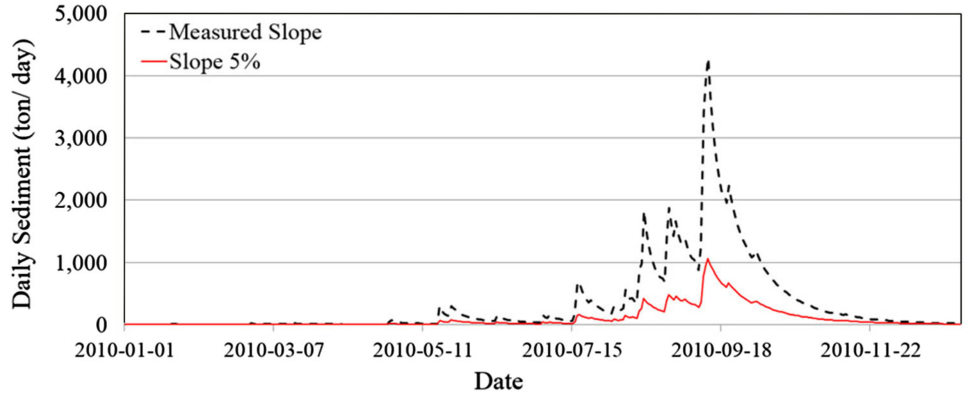


Fig. 10 Comparison of the estimated sediment for measured slope and slope 5 % (measured slope vs. slope 5 %)

carefully by considering various economic, environmental, social aspects.

Conclusions

Hydrologic variability has undermined the function of river to hydro-ecosystem and human community in a watershed. In particular, soil erosion and stream depletion have been an issue in steeply sloping watersheds due to relatively short detention time of water from rainfall events. Accordingly, this study showed the effect of watershed slope reduction on baseflow, groundwater recharge, and sediment in a steep watershed (Haean-myeon watershed) by adjusting the angle of watershed in term of engineering.

In predicting hydrologic responses, the existing SWAT model has a difficulty to reflect accurately the topography of HRU in estimating runoff and sediment in a watershed due to its structural characteristics and limitations in regions with a steep slope in particular. For these reasons, this study attempted to estimate more accurate direct flow and sediment by considering the topographic characteristics of individual HRUs through the measured slope and slope length. In addition, the spatio-temporal groundwater recharge was estimated based on the land use map constructed by using an observed crop map and the agricultural information including cultivation method, tillage, and fertilization. The results from the SWAT calibrations showed that NSE and R^2 were 0.71 and 0.8 for streamflow, and 0.58 and 0.59 for sediment, respectively. Based on a threshold suggested by Ramanarayanan et al. (1997), the results from calibrations of the SWAT model for streamflow and sediment agreed well between the simulations and the observations. However, calibration performed in this study also has some limitations. A main limitation is the lack of the observational data; only 25 data for streamflow and 20 data for sediment may be not enough to calibrate the model. In addition, only five parameters can bring uncertainty in SWAT calibration for streamflow and sediment since other parameters can affect calibration. In this regard, sufficient observational data will improve calibration and validation of the model considering the effect of other parameters.

In this study, the suggested method (the reduction of the slope angle of steep regions) contributed to the increase in the quantity of river water and decrease in sediment by increasing groundwater recharge and baseflow in the Haean-myeon watershed. These positive effects will be propagated to improvement of aquatic ecosystems environment and mitigation of stream depletion in dry season. In particular, it is expected to increase the population of primary freshwater fish such as pale chub, dark chub, Chinese minnow, Moroco kumgangensis, Ladislabia taczanowskii, oriental weatherfish, and mandarin fish in the Haean-myeon watershed. Also, the soil erosion reduced by the suggestion will sequentially decrease the quantity of phosphorus in a river and eventually eutrophication. Such improvements in water quality will restore habitat of fish and aquatic insects. Moreover, long-term water resources management considering watershed characteristics will contribute to efficient adaptation and preparation for future climate change.

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