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RESEARCH ARTICLE

Modeling the Hydrologic Responses to Land Cover and Climate Changes of Selected Watersheds in the Philippines Using Soil and Water Assessment Tool (SWAT) Model

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Abstract: Quantitative prediction of land cover and climate change impacts on hydrologic processes is widely used to develop sound watershed management strategies. However, not much is yet understood about the hydrologic behavior of watersheds in the Philippines in response to land cover change and climate variability. This study was designed to simulate the hydrologic responses of eight land cover and climate scenarios of Pagsanjan-Lumban Watershed (PLW) in Laguna, Quiaoit River Watershed (QRW) in Ilocos Norte, and Saug Watershed (SW) in Davao del Norte through the Soil and Water Assessment Tool (SWAT). Streamflow was then used to calibrate and validate the model using SUFI-2 algorithm in SWAT-CUP. The calibration exhibited a good match between observed and simulated streamflow for PLW (R2 = 0.72, NS = 0.69), QRW (R2 = 0.67, NS = 0.62), and SW (R2 = 0.78 NS = 0.77). Simulation results showed that (i) increased (decreased) precipitation in the areas also increased (decreased) water yield, surface runoff, and baseflow; (ii) the moderate shift to forest within the watershed moderately decreased runoff volume and increased evapotranspiration, which consequently decreased baseflow; (iii) urbanization resulted in lower baseflow but higher evapotranspiration; and (iv) presence of forest vegetation is associated with high infiltration and recharge; thus, lower surface runoff with higher baseflow. Hydrologic behavior, therefore, changes as it responds to changes in land cover and climate. Thus, appropriate interventions are vital to attain water security and sustainability in the watersheds.

Keywords: Hydrologic response, Land use/cover Change, Climate Change, SWAT model, SWATCUP, Streamflow

JEL Classifications: *C63, Q25, Q54*

A watershed provides water for domestic, agricultural, and ecological maintenance and services. Water is one of the basic needs not only of humans but also of every living organism in the ecosystem. However, many communities and nations around the world experience the issues on water quantity and quality brought by the changes in climate, land cover, and fast-*rising* human population (Kundzewicz et al., 2007). Hydrologic responses to land use and cover changes, land management, and climate changes are integrated indicators of the watershed condition.

In studying hydrologic characteristics of a watershed, hydrologic modeling is used. It is considered as a tool to predict the effects of human interventions and the inevitable impacts of climate change on watershed hydrology. Hydrologic modeling and water resources management studies are both related to the spatial hydrologic cycle processes. Also, land use and land cover influence watershed hydrological responses by partitioning rainfall between return flow to the atmosphere as evaporation and transpiration and flow to aquifers and rivers.

The projected intense climate will also intensify the vulnerability of most of the already vulnerable sectors of the society. Recent studies show that climate change has altered water flows and resources in river basins (Chen, Takeuchi, Xu, Chen, & Xu, 2006; Rees & Collins, 2006).

Developing a quantitative prediction model for assessing the impacts of land use and climate changes on hydrologic responses in watersheds is of paramount importance. A model can provide the basis for developing policy interventions and for developing sound watershed management schemes that ensure environmental and economic sustainability. Among the most widely used simulation modeling tools for predicting hydrologic responses is the SWAT model (Arnold, Srinivasan, Muttiah, & Williams, 1998; Gassman, Reyes, Green, & Arnold, 2007). However, predictions of the effects of land cover and climate changes in hydrology using the SWAT Model have yet to be performed in most of the Philippine watershed conditions.

The main objective of this study is to quantify the hydrologic responses to land cover and climate changes of selected watersheds.

Study Area

Located in the southeastern part of the Laguna de Bay is the Pagsanjan-Lumban Watershed (PLW). The watershed has two climatic types. Climatic Type IV prevails in the towns of Cavinti, Kalayaan, Lumban, Majayjay, Magdalena, and Pagsanjan, Laguna with rainfall more or less evenly distributed throughout the year. In some parts of Lumban and Magdalena, Climatic Type III is experienced. This is characterized by not very pronounced season, dry from November to April and wet during the rest of the year. A greater percentage of the area, about 79.6% or 32,045 hectares has a slope of ≤18%. The sloping to mountainous areas with >18% slope are approximately 8,229 hectares or 20.4% of the total area. These areas are found in the east, southeast (Sierra Madre Range) and south of the watershed going towards Mt. Banahaw. The delineated boundary of watershed resulted in an area of 40,274 hectares.

Based on the delineated boundary, the Quiaoit River Watershed (QRW) has a total land area of 17,909 km^2 covering the city of Batac and the municipalities of Paoay and Currimao. About 70% of the total watershed area is located within the City of Batac. The watershed receives an annual rainfall of about 1,664 mm with an average annual maximum and minimum temperature of 32.0°C and 20.0°C, respectively. The average annual relative humidity was observed to be 82.7%. Relief of the QRW varies from gently sloping, rolling to hilly, and mountainous starting from the lakeshore to the highland. Slopes (0-18m) of the relatively large area (around 16,000 ha or 88% of the total area) are favorable for the cultivation of crops. The remaining 12% or around 2,000 ha accounts for the highlands (>30m) and only limited areas may be cultivated for crops. The lowlands can be found in the north/west side of the watershed while the highlands can be found in south/east side.

Saug Watershed (SW) has an area of 93,859 hectares. It lies between 7º 90” and 8º 31” latitude and between 82º25” and 87º40 longitude. The majority of its area is located within the municipalities of Laak, Compostela Valley; New Corella, San Isidro, and Asuncion, Davao del Norte; Monkayo, Montevista, Nabunturan, Mawab, all of Compostela Valley; and Tagum City and Kapalong, Davao del Norte. The three largest areas of the watershed are located in Laak, New Corella, and Asuncion comprising 22.88%,

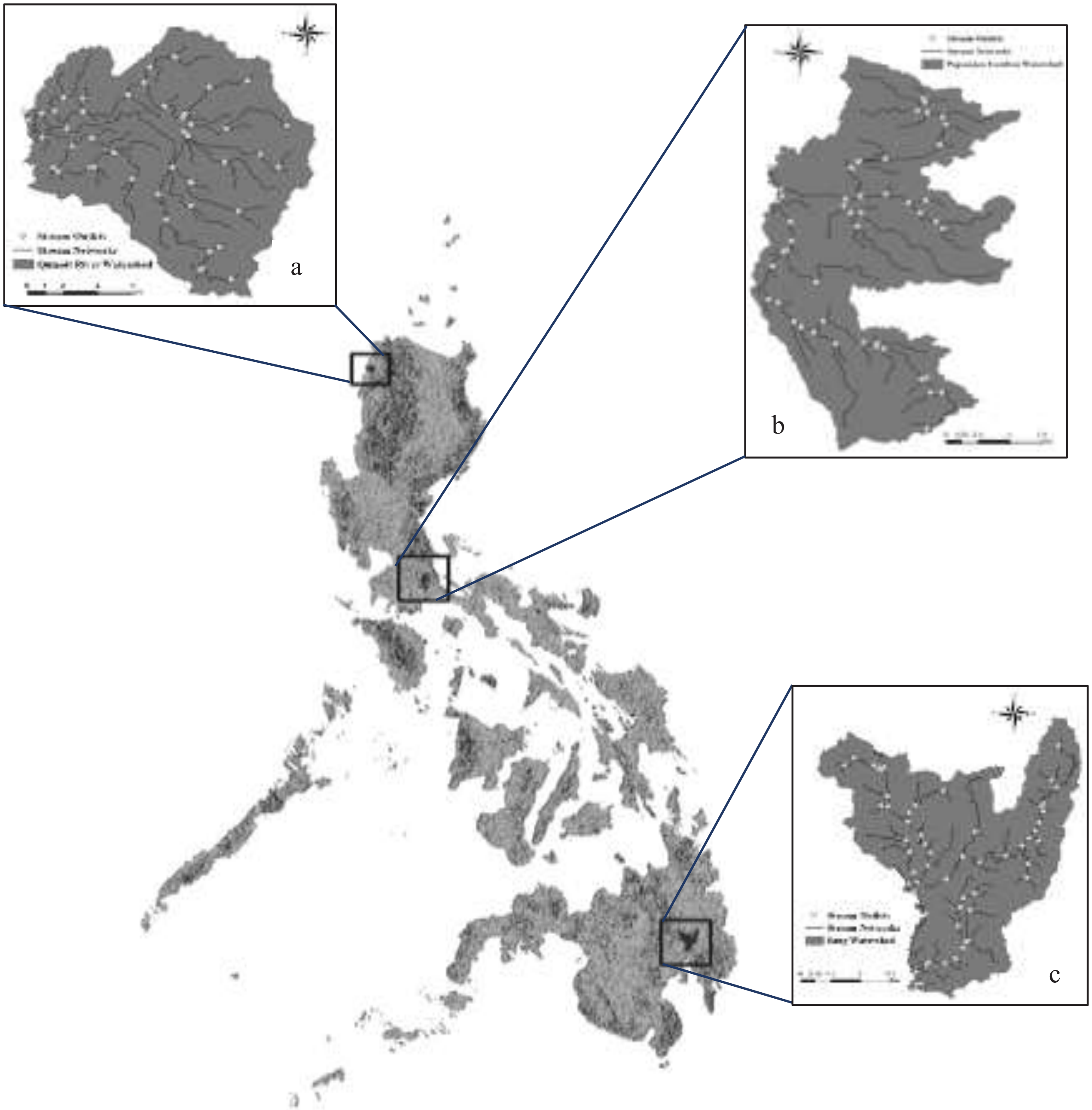

Figure 1. Location of (a) Quiaoit River Watershed, (b) Pagsanjan-Lumban Watershed, and (c) Saug Watershed.

22.43%, and 20.10%, respectively. The barangays located within the watershed include about 41 lowland barangays and 32 upland barangays.

SW belongs to Type IV Climate under Corona's Classification, characterized by no distinct dry and wet season with uniform rainfall throughout the year. The area has a more or less 2,258.2 mm of rainfall every year with an average annual maximum and minimum temperature of 31.8 °C and 22.94 °C, respectively.

Materials and Methods

SWAT Model

The SWAT model is a continuous-time, semi-distributed, process-based river basin model. It has proven effective (Gassman et al., 2007) in evaluating the effects of alternative management decisions on water resources and nonpoint source pollution (Arnold et al., 2012). As evidenced, SWAT principles are used in various regions in the world. Moreover, many of these SWAT-related studies are presented and published in peer-reviewed journals. In 2007, there were over 250 peer-reviewed literature related to SWAT applications (Gassman et al., 2007). Among these published papers were: "Assessing impacts of different land use scenarios on the water budget of Fuhe River, China using SWAT model" (Tao, Chen, Lu, Gassman, & José-Miguel, 2015); "Climate change impact assessment on hydrology of Indian river basins" (Gosain, Rao, & Basuray, 2006); and other related studies across the world. In the Philippines, some of the related literatures were: "Predicting the hydrologic response of the Laoag River basin to climate change using the SWAT model" (Alibuyog & Pastor, 2009) and "Hydrologic impact evaluation of land use and land cover change in Palico Watershed, Batangas, Philippines using the SWAT model" (Briones, Ella, & Bantayan, 2016).

The model is process-based, computationally efficient, and capable of continuous simulation over long periods (Arnold et al., 2012). Major model components describe processes, including water movement, sediment movement, plant growth, nutrients, pesticides, land management, hydrology, and soil temperature and properties (Arnold et al., 2012; Alibuyog et al., 2009). In SWAT, a watershed is divided into multiple subwatersheds and are then further subdivided into hydrologic response units (HRUs) consisting of homogeneous land use, soil characteristics, topography, and management (Arnold et al., 2012).

Many previous studies have demonstrated the ability of SWAT in detecting the impacts of land use/cover and climate change on hydrological components in different areas (Fan & Shibata, 2015; Nie et al., 2011; Guo, Hu, & Jiang, 2008; Zhou et al., 2013; Gassman et al., 2007).

Digital Elevation Model

Interferometric Synthetic Aperture Radar (IFSAR) image, which has 5 x 5 meters pixel resolution, was used. The DEM serves as the basis for delineating the watershed boundaries and stream networks of the three study areas. It was also used to derive the slope map of the watersheds.

Land Use/ Land Cover

The 2010 land cover map was used for the three study areas. These maps were obtained from the NAMRIA. Land cover mapping revealed the pattern in the different cover types of land resources and is a basis for characterizing landscape and understanding land management practices. The land cover classes in the watersheds were reclassified to conform to the SWAT land use/cover database.

Based on the SWAT database, the generalized land cover map of PLW presented seven classes: AGRL (agricultural land), BARR (barren land), FRST (forest), PAST (pasture), RNGB (range-brush), URBN (urban), and WATR (water). The watershed is mostly covered by agricultural land. On the other hand, QRW land cover was reclassified into six classes: AGRL, BARR, FRST, RNGB, URBN, and WATR. The QRW is also dominated by AGRL followed by RNGB. Similarly, after reclassifying the land cover map of SW, the area seems mostly covered with AGRL. Other land cover classes of SW are FRST, RNGB, URBN, and WATR. The three study areas are dominantly covered by agricultural land.

Soil

Soil map is a geographical representation of the diversity of soil types and/or soil properties in the areas of interest.

For this study, the soil maps from the Bureau of Soil and Water Management (BSWM) were used. Following the required format of the model, a soil user table was prepared for the SWAT model to read.

Luisiana soil series, Bantay soil series, and Camansa soil series are the most common soil types in PLW, QRW, and SW, respectively. Luisiana soil series has a texture of sandy clay loam, while Bantay soil is considered as clay loam soil; the texture of Camansa soil series is also sandy clay loam. Based on the texture, Luisiana and Camansa soil series have better drainage and infiltration than Bantay soil series.

Weather Data

The daily weather data from 1986 to 2013, collected from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), was used as model inputs. The weather data included rainfall, maximum and minimum temperature, solar radiation, relative humidity, and wind speed.

Streamflow Records

Streamflow data from the previous program implemented in PLW was acquired and used for this study since there was no available streamflow data from the Department of Public Works and Highways (DPWH). For QRW and SW, secondary data from the DPWH and previous studies were used. The discharge data for QRW was collected from the station at Poblacion, Batac, Ilocos Norte, while the discharge data for SW was collected from the Saug River Station located in Asuncion, Davao del Norte.

The streamflow data obtained for PLW covered 1995 up to 2004, QRW had 1986 to 1991 set of data, and SW streamflow data was from 2001 to 2013. Availability of streamflow data, though limited, enabled performing the calibration and validation of the model in this study. It is important to note when comparing the simulated water budget of the three watersheds as influenced by land use and land cover change, that the streamflow datasets used for running SWAT do not cover the same time period and hence could significantly affect the results of simulation runs.

Setting-up SWAT Model

The SWAT model used to simulate the hydrologic water balance was implemented in the ArcSWAT Version 2012.10_2.19 software.

Aided by the ArcSWAT software, the watershed boundary and river networks of the three study areas were delineated based on their 5 x 5 meters IFSAR. In this study, the threshold values used were site-specific based on the identified stream network.

The delineated boundary of PLW resulted in an area of 40,274 hectares, while QRW and SW had areas of 17,909 and 93,859 hectares, respectively. The delineated watersheds were used for the entire hydrologic modeling.

More so, based on the DEM-based delineation of the watersheds, PLW had a total of 101 sub-basins and 1,543 HRUs. The Quiaoit River Watershed had 95 sub-basins and 1,502 HRUs, while SW had 115 sub-basins and 1,824 HRUs. The HRUs were created as a function of site-specific land cover classes, soil classes, and five slope classes (0 to 8%, 8% to 18%, 18% to 30%, 30% to 50%, and 50% and above).

Hydrologic response units are sub-watershed units treated as homogenous blocks of land use, management techniques, and soil properties (Arnold et al., 1998; Hjelmfelt, 1991). To prevent dissolving minor land uses, slope, and soil types, a zero percent threshold value was considered.

The weather data, specifically rainfall, maximum and minimum temperature, soil, and land cover/use data were written as text files and the ArcSWAT format requirement was followed.

As mentioned by Rathjens (2012), according to Neitsch, Arnold, Kiniry, Srinivasan, and Williams (2011), the calibration of streamflow can be performed in two consecutive steps. First, calibrate the model for annual average and second, calibrate to monthly or daily time step to fine-tune the calibration.

For this study, streamflow data was used to calibrate the model using the monthly time step. The calibration and validation were performed using SWAT Calibration and Uncertainty Program (SWAT CUP). The observed and simulated streamflows were compared. To obtain an adequate goodness of fit, the coefficient of determination (R^2) and Nash-Sutcliffe model efficiency (NS) were evaluated during the model calibration and validation.

Model Evaluation

The simulated and observed streamflows were summarized on a monthly basis. The difference between the simulated and observed values was compared. The goodness of fit was evaluated by R^2. The efficiency of the model was evaluated based on the streamflow values through the Nash and Sutcliffe (1970) equation. The equation is given as:

$$NS = 1 - \frac{\sum_{i=1}^{n}(X_{mi} - X_{pi})^2}{\sum_{i=1}^{n}(X_{mi} - X_{m})^2}$$

where:

NS = efficiency of the model
X_{mi} = measured value of the streamflow, m^3/s
X_{pi} = predicted value of the streamflow, m^3/s
X_m = average measured value of the streamflow, m^3/s

The Nash–Sutcliffe model efficiencies can range from $-\infty$ to 1. A value of NS=1.0 indicates a perfect prediction, that is, perfect match of modeled discharge to the observed data while negative values indicate that the predictions are less reliable and that the observed mean is a better predictor than the model. An efficiency of 0 ($NS = 0$) indicates that the model predictions are as accurate as the mean of the observed data. Essentially, the closer the model efficiency is to 1, the more accurate the model is.

In the study of Luo (2011), the best calibration and parameter uncertainty is measured on the basis of the closeness of the P-factor to 100% (i.e. all the observations bracketed by the prediction uncertainty) and the R-factor of 1 (i.e., achievement of a rather small uncertainty band).

Land Cover and Climate Change Scenarios

The calibrated model was used to simulate various land cover and climate scenarios. This was done to determine the effects of land cover and climate changes on the hydrologic water balance of the watersheds. Ideally, land cover scenarios are developed using land use change models that take into account the influences of climate, policies and other drivers of land use change. However due to limitation of time and resources, arbitrarily set incremental land use and land cover scenarios were instead used.

Table 1 shows the summary of the different land cover and climate scenarios used in the study. For each scenario, a certain percentage of the existing forest cover was converted into agricultural land and some range-brush land was converted into forest land. A 10% increase in the amount of rainfall was also applied.

Furthermore, the 2050 projected provincial change in rainfall generated by PAGASA was adopted. Scenarios on urbanization and forest rehabilitation were also simulated along with the 2050 projected rainfall. These scenarios were included to predict the potential impacts of such changes with specific objectives on hydrologic components of the watershed.

Results and Discussion

Calibration, Validation, and Uncertainty Analysis

To perform the calibration and validation of the model, six parameters were selected: Initial SCS runoff curve number (CN2), Base-flow alpha factor (ALPHA_BF), Groundwater delay time (GW_DELAY), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Groundwater "revap" coefficient (GW_REVAP), and Soil evaporation compensation factor (ESCO). These are typically the parameters also found to be sensitive by other researchers such as van Griensven et al. (2006), Jha, Pan, Takle, and Gu (2004), and Di Luzio, Srinivasan, and Arnold (2004).

The calibration showed that the SWAT model satisfactorily captured the observed streamflow of the test watersheds with R^2 of 0.72, 0.67, and 0.78 for PLW, QRW, and SW respectively. The NS value obtained for PLW was 0.69, while for QRW it was 0.62 and 0.77 for SW. The goodness of fit of the model as indicated by R^2 and NS values were all satisfactory.

Further, the peak flows in November 2001 and December 2003 and low flow in July 2002 for PLW do not correspond with high rainfall events (Figure 2). Hence, it was suspected that the flow observed during those months was erroneous. This affected the R^2 and NS values. The fair R^2 and NS and overestimation in QRW are apparent in Figure 4 where simulated peak flow during October 1986 and simulated low flow during August 1986 did not correspond with the recorded rainfall. The simulated peak flow also justified the overestimation of simulated over observed data. A better model performance can be

Table 1. *Summary of Different Land Cover and Climate Scenarios*

Scenario	Existing Land Cover			Rainfall
	FRST	AGRL	RNGB	
1			50% to FRST	10% increase
2			75% to FRST	10% increase
3			100% to FRST	10% increase
4	10% to AGRL		50% to FRST	10% increase
5	10% to AGRL		75% to FRST	10% increase
6				2050 projected rainfall
7		50% to URBN	25% to URBN	2050 projected rainfall
8		50% to FRST	100% to FRST	2050 projected rainfall

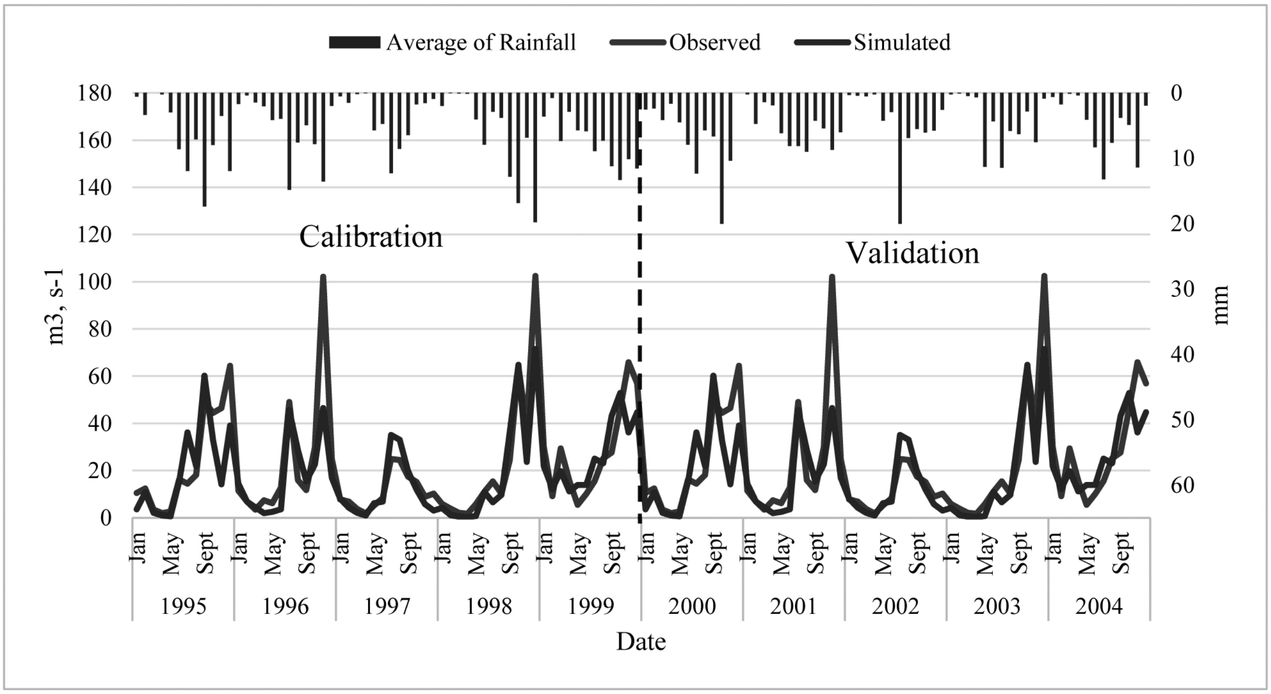

Figure 2. SWAT calibration (1995–1999) and validation (2000–2004) simulations plotted against observed streamflow data of Pagsanjan-Lumban Watershed.

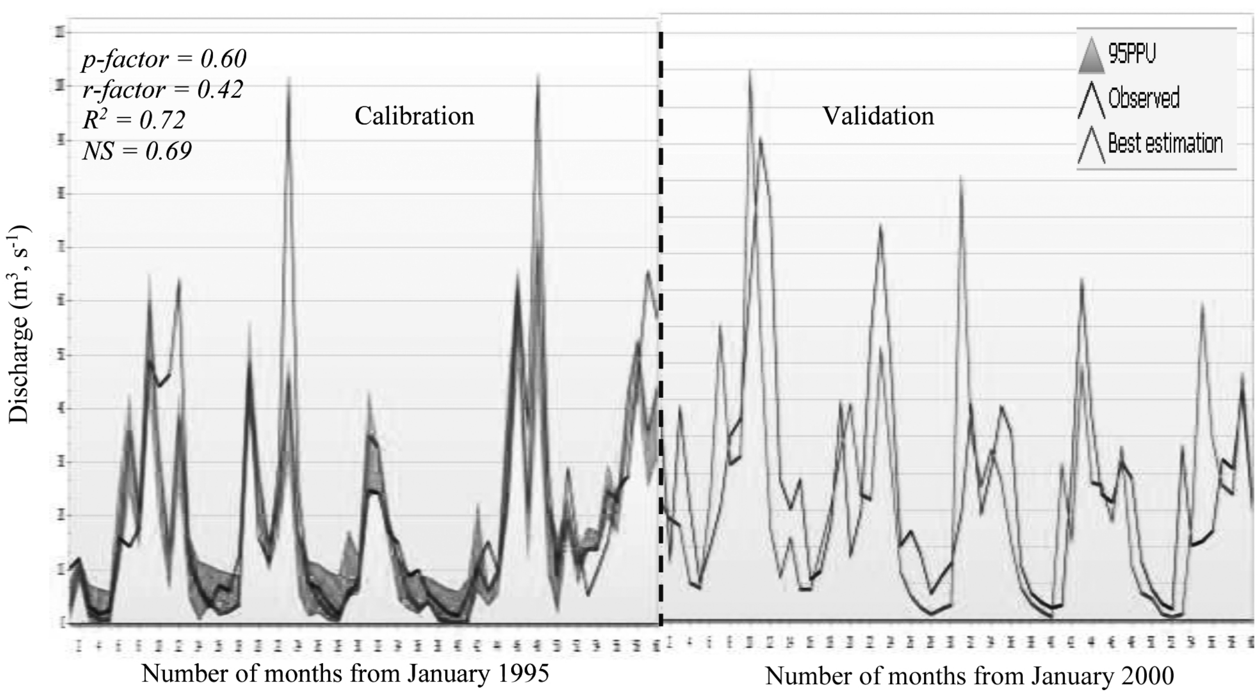

Figure 3. Uncertainty analysis of Pagsanjan-Lumban Watershed using SWAT CUP showing 95% prediction uncertainty (95PPU), P-factor, R-factor, NS and R2 values.

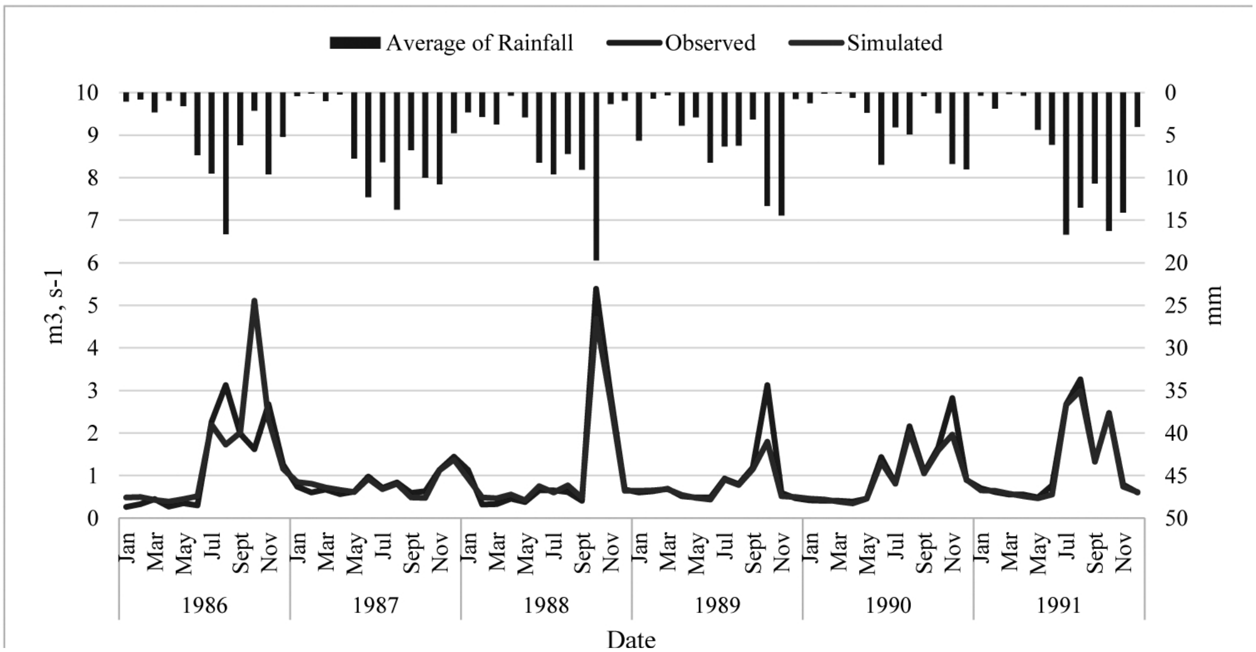

Figure 4. SWAT calibration (1986–1988) and validation (1989–1991) simulations plotted against observed streamflow data of Quiaoit River Watershed.

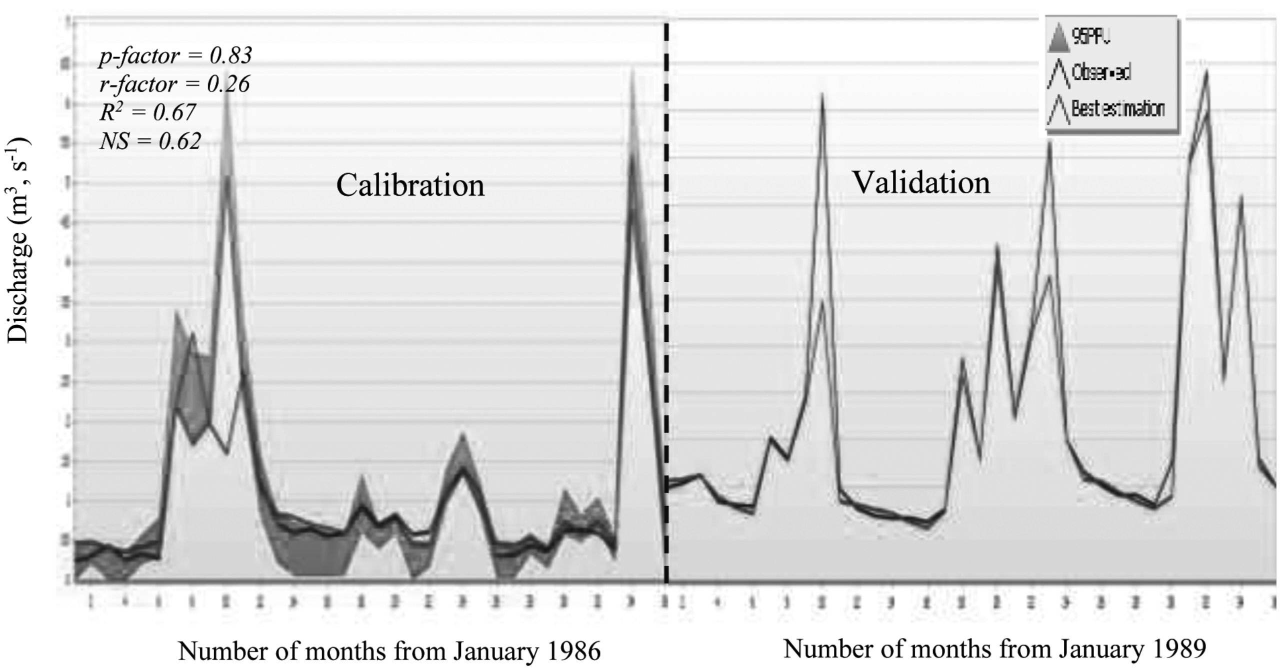

Figure 5. Uncertainty analysis of Quiaoit River Watershed using SWAT CUP showing 95% prediction uncertainty (95PPU), P-factor, R-factor, NS and R2 values.

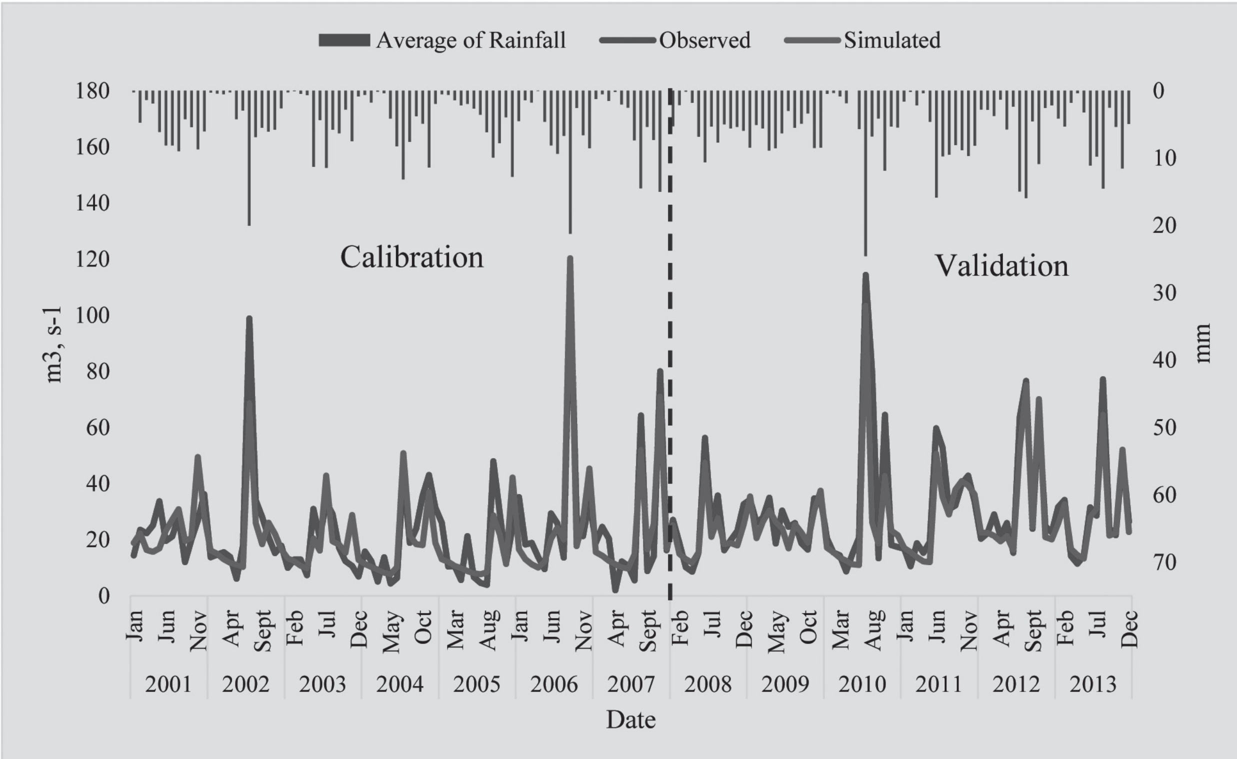

Figure 6. SWAT calibration (2001–2007) and validation (2008–2013) simulations plotted against observed streamflow data of Saug Watershed.

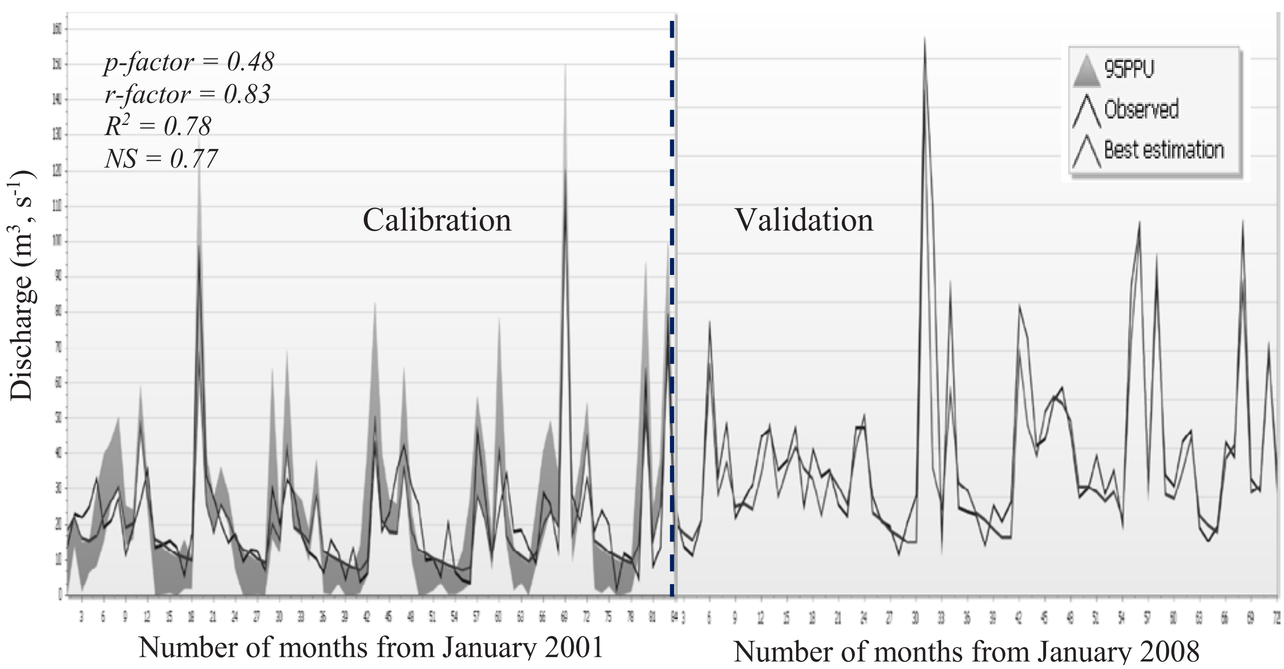

Figure 7. Uncertainty analysis of Saug Watershed using SWAT CUP showing 95% prediction uncertainty (95PPU), P-factor, R-factor, NS and R2 values.

Table 2. *Summary of Calibration and Validation Statistical Indices*

Indices	Calibration			Validation		
	Pagsanjan-Lumban	Quiaoit River	Saug	Pagsanjan-Lumban	Quiaoit River	Saug
NS	0.69	0.62	0.77	0.69	0.89	0.81
R^2	0.72	0.67	0.78	0.72	0.92	0.83
p-factor	0.60	0.83	0.48	0.60	0.89	0.36
r-factor	0.42	0.26	0.83	0.42	0.00	0.00
PBIAS	14.1	-5.4	5.6	14.1	8.3	9.6

Table 3. *SWAT Parameters Used to Calibrate the Model*

Parameter	Initial Range/Value	Fitted Values		
		PLW	QRW	SW
CN2	-0.2– 0.2	-0.030	-0.190	-0.190
ALPHA_BF	0.0–1.0	0.775	0.025	0.025
GW_DELAY	30.0–450.0	40.500	292.500	292.500
GWQMN	0.0–2.0	0.550	0.1500	0.1500
GW_REVAP	0.0–0.2	0.055	0.135	0.135
ESCO	0.8–1.0	0.995	0.935	0.935

Note: CN2 - Initial SCS runoff curve number.
ALPHA_BF - Base-flow alpha factor
GW_DELAY - Groundwater delay time
GWQMN - Threshold depth of water in shallow aquifer required for return flow to occur
GW_REVAP - Groundwater "revap" coefficient

achieved when calibration data is increased rather than use more distributed model parameters (Tarasova, Knoche, Dietrich, & Merz, 2016). The high R^2 and NS of SW is attributed to the apparent good match between observed and simulated streamflow (Figure 6). Moreover, the peak flows also corresponded with rainfall event.

The calibration results were improved after performing the validation (Table 2). The R^2 of QRW and SW improved to 0.92 and 0.83, respectively. Higher NS values of 0.89 for QRW and 0.81 for SW were also obtained. The calibration yielded the same values (R^2 = 0.72, NS = 0.69) for PLW.

In modeling, uncertainties are common. They can be due to model uncertainty or input uncertainty. In this study, the uncertainty was measured by P-factor and R-factor. For PLW, calibration and validation generated the same P-factor of 0.60 and R-factor of 0.42. On the other hand, for QRW, results of validation (P-factor = 0.89, R-factor = 0.00) improved over calibration (P-factor = 0.83, R-factor = 0.26). The same was true for SW as calibration results (P-factor = 0.48, R-factor = 0.83) improved during validation (P-factor = 0.36, R-factor = 0.00). The P-factor represents the observed data that is within the 95PPU bracket, while R-factor indicates the thickness of the band. Corresponding to the desirable results of goodness of fit and uncertainty analysis, the model was used to simulate effects of different land cover and climate changes on hydrologic responses of the three watersheds.

For PLW, P-factor and R-factor were not high due to input uncertainty, that is, the two observed peak flows during October 1996 and November 1999 were outside the 95PPU bracket as shown in Figure 3.

The data points that were not captured by the 95PPU were considered the error. And the percent error is the difference between 1 and the value of P-factor. According to Abbaspour (2007), the narrower the value of parameter ranges, the narrower the 95PPU envelop, hence, the smaller P-factor and R-factor. This was illustrated in Figure 3 wherein the fitted values of each parameter derived from calibration were used as the new range of parameters for validation. A larger P-factor can be achieved at the expense of a larger R-factor. Percent bias (PBIAS) is the measurement of the average tendency of the simulated data to be larger or smaller when compared with the observed data. The simulation generated a PBIAS of 14.4, which means there was a 14.4% underestimation of the observed data.

The results of P-factor and R-factor for QRW were beyond the desirable index. The high P-factor demonstrates that most of the observed data were within the 95PPU band, while the low R-factor values implied thick 95PPU band, that is, degree of uncertainty. The zero R-factor obtained in validation suggests that simulated data agreed with the observed data. The PBIAS value during validation confirmed that there was an 8.3% model underestimation.

In the real world, we aim to capture as much observable data as possible within a certain 95PPU band, that is, achieve a P-factor close to 1.0 with an uncertainty band as thin as possible (R-factor close to 0).

During the calibration of SW, despite a very thick bracketing of 0.83, only 48% of the observed data were within the uncertainty band (Figure 7). However, this improved in the validation after supplying the fitted values of the parameters identified (Table 3). The model also underestimated the observed values by 5.6% during calibration and by 9.6% during validation.

Initially, the SWAT default values for each parameter were used for calibration. The new parameter settings derived from model calibration were used to re-write the model inputs and re-run SWAT model (Table 3).

Water Balance

Supported with NS and R^2 results, there is a strong justification for using the fitted values of the identified parameters as input to hydrologic modeling efforts for the entire watershed to assess watershed responses to land use and climate changes (Miller et al., 2002; Srinivasan, Zhang, & Arnold, 2010).

Based on the result, the average annual rainfall from 1991 to 2013 in PLW was about 2,129.1 millimeter. Approximately 44.70% of this was lost as surface runoff. About 20.86% was percolated into the soil profile, while evapotranspiration accounted for about 31.17%. The rest was converted as lateral flow. The average potential evapotranspiration was about 1,279.9 millimeter per year. The evaporation from shallow aquifer was about 0.05 millimeter per year. The watershed has also a return flow capacity of 420.07 millimeter per year.

Table 4. *Pagsanjan-Lumban Watershed Water Budget*

Hydrologic Variables	Values (mm)
Precipitation	2129.1
Surface Runoff	951.62
Groundwater (Deep Aquifer)	21.76
Groundwater (Shallow Aquifer)	420.07
Percolation	444.81
Evapotranspiration	663.6
Potential Evapotranspiration	1279.9
Deep Aquifer Recharge	442.23

Table 5. *Quiaoit River Watershed Water Budget*

Hydrologic Variables	Values (mm)
Precipitation	2091
Surface Runoff	848.39
Groundwater (Deep Aquifer)	26.94
Groundwater (Shallow Aquifer)	511.9
Percolation	1449.95
Evapotranspiration	644
Potential Evapotranspiration	1697.0
Deep Aquifer Recharge	26.93

Based on calibrated model of QRW, the average annual rainfall from 1980 to 2013 in the QRW was about 2,091 millimeter. About 40.57% of this was lost as surface runoff. About 25.76% was percolated into the soil profile, while evapotranspiration accounted for 30.80%. The rest was converted as lateral flow.

The average potential evapotranspiration was about 1,697 millimeter per year. The evaporation from shallow aquifer was about 1.31 mm per year. The watershed also has a return flow capacity of 511.9 millimeter per year.

Further, the average annual rainfall in SW from 1991 to 2013 was about 2,085.9 millimeter. About 21.75% of this was lost as surface runoff. About 26.22% was percolated into the soil profile while evapotranspiration accounted for 45.34%. The rest was converted into lateral flow. The average potential evapotranspiration was about 1,772.5 millimeter per year. The evaporation from shallow aquifer was about 1.07 millimeter per year. The watershed had a return flow capacity of 518.09 millimeter per year.

Table 6. *Saug Watershed Water Budget*

Hydrologic Variables	Values (mm)
Precipitation	2085.9
Surface Runoff	453.62
Groundwater (Deep Aquifer)	27.2
Groundwater (Shallow Aquifer)	518.09
Percolation	560.57
Evapotranspiration	945.7
Potential Evapotranspiration	1772.5
Deep Aquifer Recharge	27.34

Hydrologic Impacts of Land Cover and Climates Changes

To assess the effects of climate change land conversion on surface runoff, base flows, and evapotranspiration in the study area, the calibrated model was run to simulate various scenarios.

Figure 8 shows the effects of various scenarios on the hydrologic processes of the Pagsanjan-Lumban watershed, particularly on surface runoff, baseflow, and evapotranspiration. Apparently, an increase in precipitation, as simulated in scenarios 1 to 5, increased the amount of surface runoff, baseflow, and evapotranspiration. On the other hand, the decrease in precipitation, scenarios 6 to 8, also reduced the amount of surface runoff, baseflow, and evapotranspiration. Precipitation is the key in determining water yield characteristics (Brooks, Ffolliott, Gregersen, & Thames, 1991). According to Alibuyog and Pastor (2009), changes in the precipitation will have a

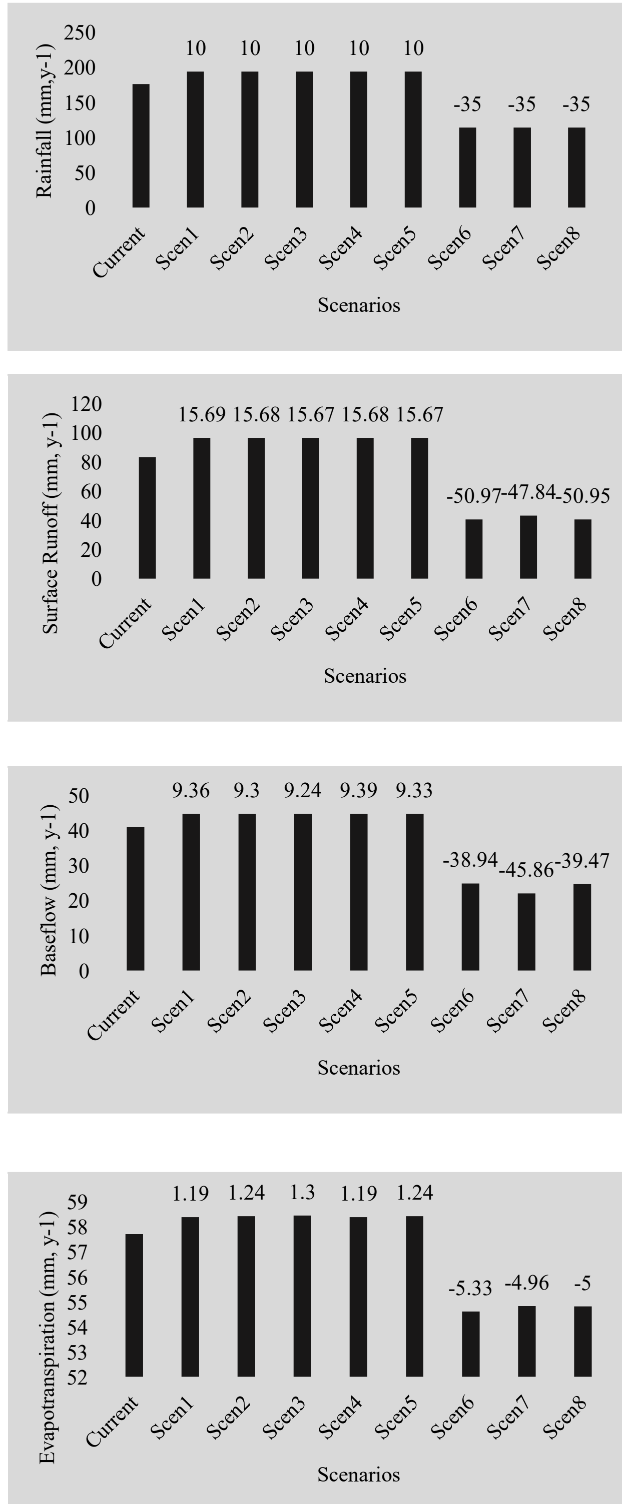

Figure 8. Simulated rainfall (mm yr-1), surface runoff (mm yr-1), base flow (mm yr-1), and evapotranspiration (mm yr-1) for various scenarios in Pagsanjan-Lumban Watershed (The values above the bars indicate the percentage change from current values).

significant impact on streamflow, runoff, and water yield. In the study conducted by Prasanchum and Kangrang (2017), surface runoff increased due to increase in rainfall.

Scenario 1, converting 50% range-brush land into forest with a 10% increase in rainfall, resulted in a 15.69% increase of surface runoff along with escalation in baseflow by 9.36% and in evapotranspiration by 1.19%. When 75% of range-brush land was converted into forest with a 10% increase in rainfall (scenario 2), surface runoff, baseflow and evapotranspiration increased by 15.68%, 9.30%, and 1.24% relative to their original levels, respectively. Moreover, when all range-brush land was converted into forest with a 10% increase in rainfall, surface runoff increased by 15.67%, baseflow increased by 9.24%, and evapotranspiration increased by 1.30%.

The three scenarios revealed the inverse relationship between forest cover and baseflow due to evapotranspiration. In this study, when forest cover was increased, it yielded higher evapotranspiration, thus, reducing baseflow. Furthermore, scenarios 1 to 3 also showed that in Pagsanjan-Lumban Watershed, surface runoff dwindled as forest cover increased. Forest vegetation reduces the energy of raindrops, consequently reducing runoff velocities and erosion. The presence of forest cover increases infiltration, which lessens runoff.

In scenario 4, 50% conversion of range-brush to the forest and 10% forest to agriculture combined with 10% increase in rainfall led to a 9.39% increase in baseflow than current levels. Evapotranspiration also increased by 1.19%, while surface runoff was 15.68% greater than the current level. Scenario 5 is almost the same as scenario 4 except that 75% of range-brush was converted into forest. Scenario 5 also showed increases in surface runoff, baseflow, and evapotranspiration by 15.67%, 9.33%, and 1.24% than present levels. Scenarios 4 and 5 demonstrate that when 75% of range-brush is converted to forest, evapotranspiration is higher. However, baseflow is lower only when 50% of range-brush is altered into the forest.

The impact of increasing forest cover on surface runoff and other hydrologic components seemed to be minimal. This could be attributed to percent land area coverage of range/brush land and forest. Range/brush land and forest only occupy 10.13% and 5.08% of the total area, respectively. The results are also consistent with some studies (Lahmer, Pfiitzner, & Becker, 2001; Guo et al., 2008; Tao et al., 2015) wherein moderate land use changes resulted in only small changes of various water balance components.

By 2050, PAGASA projects the rainfall in Laguna province to decrease by 34.8%. In scenario 6, a 35% decrease in rainfall with no changes in land cover was simulated. Results showed that given the same land cover condition in the watershed, decreased rainfall caused significant reduction in surface runoff, baseflow, and even evapotranspiration by 50.97%, 38.94%, and 5.33%, respectively. The decrease in baseflow due to a decrease in rainfall is critical since baseflow provides dependable flow for irrigation and domestic use during dry months.

Scenario 7 simulated the effect of urbanization and climate change on hydrologic processes. Declining rainfall combined with urbanization of the watershed resulted in a lesser surface runoff, baseflow, and evapotranspiration by 47.84%, 45.86%, and 4.96%, respectively. Between scenario 6 (decreased rainfall) and scenario 7 (decreased rainfall and urbanization), surface runoff was 3.13% higher in scenario 7 than in scenario 6. Moreover, the baseflow in scenario 7 is lesser by 6.92%. In Leopold's (1968) commonly cited urban hydrology guidebook, urbanization tends to flush water quickly due to reduced hydraulic resistance of land surfaces, which is a consequence of impervious surface area and compacted soils.

In scenario 8, all range-brush and 50% of agriculture was converted to forest with a 35% decrease in rainfall. Results revealed that surface runoff decreased by 50.95%, with a 39.47% decline in baseflow and 5% reduction in evapotranspiration. With the projected drop in rainfall by 2050, urbanization of the area yielded a 3.11% higher surface runoff with 6.39% lesser baseflow than rehabilitation of forest. The result is consistent with the study conducted by Prasanchum and Kangrang (2017), wherein the decrease in forest areas and increase in sugarcane and urban areas resulted in higher surface runoff.

Figure 9 shows the results of the simulated scenarios for QRW. The increase in precipitation produced higher surface runoff, baseflow, and evapotranspiration. When 50% of range-brush was changed into forest with a 10% increase in rainfall, surface runoff increased by 16.20% from its current volume. The baseflow and evapotranspiration also increased by 9.76% and 2.08%,

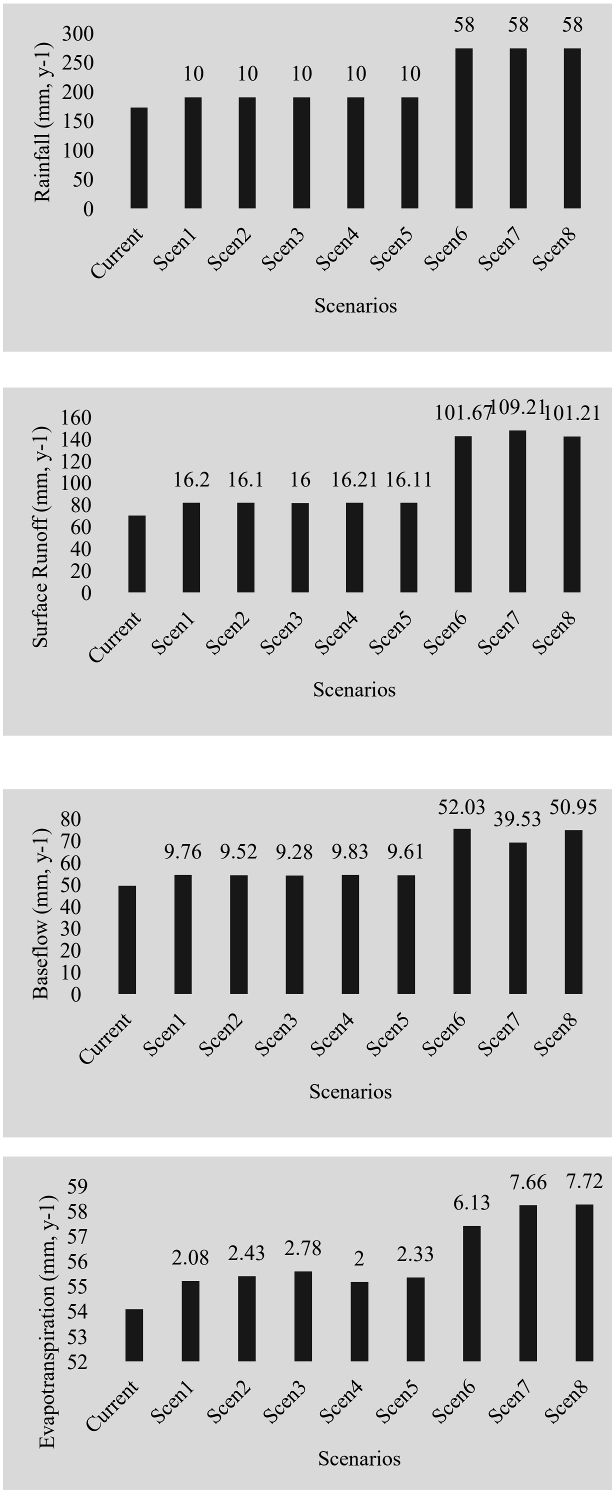

Figure 9. Simulated rainfall (mm yr-1), surface runoff (mm yr-1), base flow (mm yr-1), and evapotranspiration (mm yr-1) for various scenarios in Quiaoit River Watershed (The values above the bars indicate the percentage change from current values).

respectively. In Scenario 2, 75% of range-brush was converted to forest resulting in a 10% increase in rainfall, a 16.10% increase in surface runoff, baseflow that was higher by 9.52%, and evapotranspiration that increased by 2.43%. When all range-brush was converted into forest, the simulation predicted a 10% increase in rainfall, while surface runoff, baseflow, and evapotranspiration increased by 16%, 9.28%, and 2.78%, respectively.

The three scenarios suggest that larger forest area coverage led to lower surface runoff as more forest cover tended to improve infiltration. Moreover, evapotranspiration was at its highest, and baseflow at its lowest, in scenario 3 where 100% of range-brush was converted into forest with more vegetation. These results are consistent with many studies that have observed links between higher watershed forest cover and lower baseflows, which can be attributed to high evapotranspiration rates of forests (Price, 2011; Guo et al., 2008).

The increase in runoff despite converting range-brush land to forest could be due to the topography and soil properties of range-brush land, which can comprise of steep slopes with clay loam soil. Since clay loam is a soil mixture with more clay over the other types of minerals and very small particles, the movement of water through soil is slower; thus, we can expect a slower infiltration rate as more water tends to be lost to runoff. Additionally, steep upper slopes are likely characterized by coarser, less developed, and thinner soils, thereby more rapidly transmitting water (Price, 2011).

In scenario 4, the conversion of 50% range-brush to the forest and 10% forest to agriculture led to a 10% increase in rainfall and an increase in surface runoff by 16.21%. Meanwhile, baseflow and evapotranspiration increased by 9.83% and 2%, respectively. On the other hand, scenario 5 yielded 16.11% higher surface runoff from the baseline, 9.61% greater baseflow, and 2.33% increased evapotranspiration. Surface runoff is higher in scenario 4 where there is lesser forest cover; consequently, evapotranspiration is down by 0.33% with 0.22% escalated baseflow. This is because the deep rooted forest plants pull soil moisture into the soil faster than the water transpired by short rooted agricultural plants or bare soils (Guo et al., 2008). The results are also consistent with some studies

(Lahmer et al., 2001; Guo et al., 2008; Tao et al., 2015) which found that land use changes resulted only in small changes of various water balance components.

In 2050, rainfall is projected to increase by 58% in the Ilocos Province. This possible increase in rainfall was simulated in the SWAT model as scenario 6 to assess the potential impact of increased rainfall on the hydrologic behavior of QRW. Based on the simulation, a 58% increase in rainfall with no changes in the current state of land use/cover significantly increased surface runoff by 101.67%, while baseflow and evapotranspiration also increased by 52.03% and 6.13%, respectively. The increase in surface runoff is alarming as such an amount can lead to serious flooding, loss of soil nutrients, and siltation. Increased baseflow in scenario 6 is essential for irrigation, especially during dry months in the area.

Scenario 7 simulated the effects of urbanization, taking into account rainfall projected for 2050, on some of the hydrologic components of the watershed. Based on the results, surface runoff increased by 109.21%. This increase could be attributed to increased rainfall and impervious surfaces and compacted soils caused by urban development. Moreover, evapotranspiration increased by 7.66%, while baseflow only increased by 39.53%.

In scenario 8, forest rehabilitation was simulated, converting all range-brush lands and 50% of agriculture into forest. A 58% increased rainfall was factored in. The simulated scenario showed an increase in surface runoff by 101.21%, while baseflow increased by 50.95%, and evapotranspiration by 7.72%.

A comparison between scenarios 7 and 8 showed that surface runoff is higher by 8% when the area shifted towards urbanization. Furthermore, urbanization resulted in 11.42% lower baseflow. The assumption that increased impermeable surface decreases infiltration, recharge, and baseflow was found to be true in this case. On the other hand, higher evapotranspiration was observed in scenario 8 since forest cover has larger leaf areas at which transpiration can take place. Forest vegetation increases evapotranspiration rates (Schwab, Fangmeier, Elliot, & Frevert, 1993). In addition, it can be assumed in scenario 8 that the presence of forest vegetation is associated with high infiltration and recharge; thus, lower surface runoff with higher baseflow.

In addition, Figure 10 shows the results of

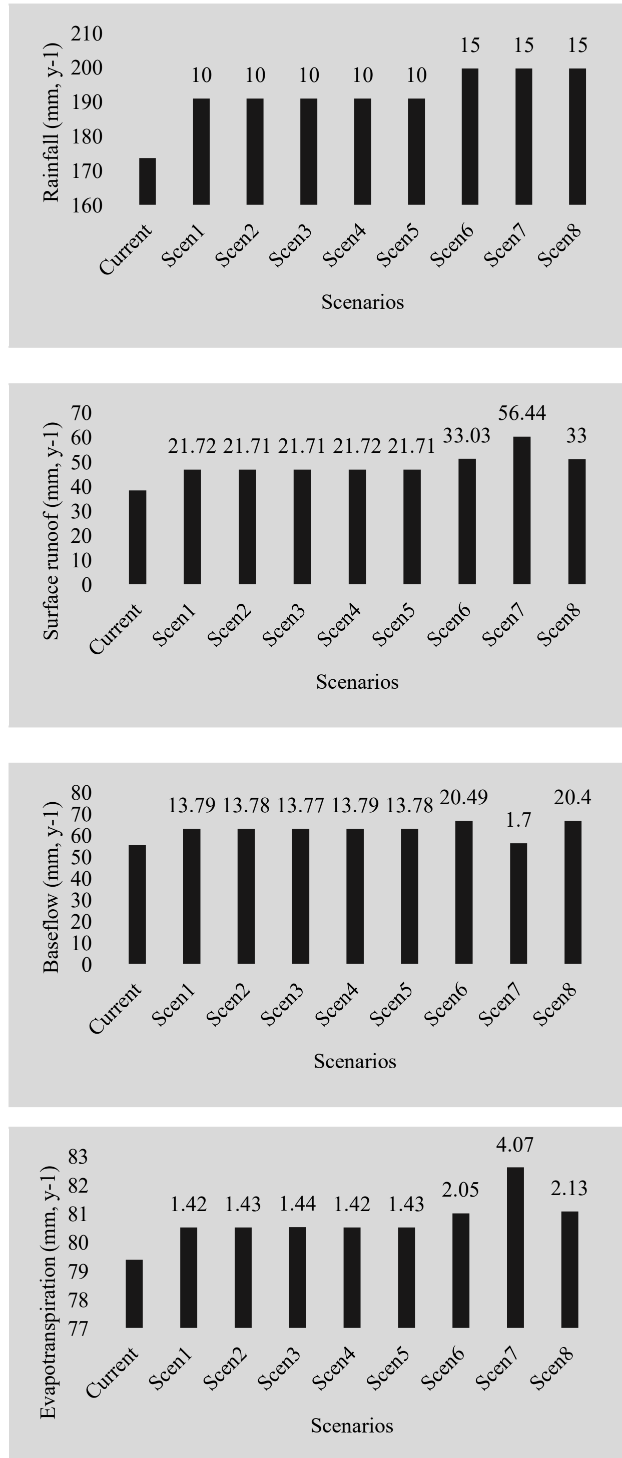

Figure 10. Simulated rainfall (mm yr-1), surface runoff (mm yr-1), base flow (mm yr-1), and evapotranspiration (mm yr-1) for various scenarios in Saug Watershed (The values above the bars indicate the percentage change from current values).

the simulated scenarios for SW. The increase in precipitation produced higher surface runoff, baseflow, and evapotranspiration. When 50% of range-brush was changed into forest with a 10% increase in rainfall, the surface runoff increased by 21.72% relative to baseline. The baseflow and evapotranspiration also increased by 13.79% and 1.42%, respectively.

In scenario 2, 75% range-brush was converted to forest with a 10% increase in rainfall; this led to an increase in surface runoff by 21.71%, an increase in baseflow by 13.78%, while evapotranspiration increased by 1.43%. When all range-brush was altered into forest with a 10% increase in rainfall, surface runoff, baseflow, and evapotranspiration increased by 21.71%, 13.77%, and 1.44%, respectively.

As seen in the first three scenarios, a 75% and 100% conversion of range-brush into the forest produced similar increases in surface runoff. The runoff is lower when only 50% of range-brush was changed into the forest. The larger forest cover tends to improve infiltration. Moreover, evapotranspiration increased as forest cover increases; forest cover was highest in scenario 3 where 100% of range-brush was converted into forest. Scenario 3 had the lowest baseflow as implied by the presence of greater forest vegetation. The result is consistent with many studies (Price, 2011; Guo et al., 2008) where the higher watershed forest cover was associated with lower baseflows due to high evapotranspiration rates of forests.

In scenario 4, the conversion of 50% range-brush to forest and 10% forest to agriculture with a 10% increase in rainfall led to an increase in surface runoff by 21.72%. Meanwhile, baseflow and evapotranspiration increased by 13.79% and 1.42%, respectively. On the other hand, scenario 5 yielded 21.71% higher surface runoff relative to the baseline, 13.78% greater baseflow, and a 1.43% increase in evapotranspiration. Surface runoff was higher in scenario 4 with less forest cover, and, subsequently, lower evapotranspiration by 0.01%, and a 0.01% increase in baseflow. This is because deep rooted forest plants entice soil moisture faster than the water transpired by short rooted agricultural plants or bare soils (Guo et al., 2008).

The negligible change in the values of the results confirms some studies (Lahmer et al., 2001; Guo et al., 2008; Tao et al., 2015) that showed how moderate land use changes resulted in only small changes of various water balance components.

By 2050, PAGASA projects rainfall to increase by 15% in Davao del Norte. This possible increase in rainfall was simulated in the SWAT model as scenario 6, which assesses the potential impact on the hydrologic behavior of the watershed. As seen in the simulation, a 15% increase in rainfall with no changes in the current state of land use/cover significantly increased surface runoff by 33.03%, while baseflow and evapotranspiration also increased by 20.49% and 2.05%, respectively. Increased baseflow in scenario 6 is essential for irrigation, especially during dry months in the area.

Scenario 7 simulated the effects of urbanization with 2050 projected rainfalls on some of the hydrologic components of the watershed. As a result, surface runoff increased by 56.44%. The increase could be due to increased rainfall and impervious surfaces and compacted soils caused by roads, building, rooftops, among other types of urban infrastructure. Moreover, evapotranspiration also increased by 4.07%, while baseflow only increased by 1.70%. Scenario 8 simulated forest rehabilitation, specifically, converting all range-brush and 50% of agriculture into forest with 15% increased rainfall. The simulation led to an increase in surface runoff by 33%, while baseflow increased by 20.40%, and evapotranspiration, by 2.13%.

Comparing scenarios 7 and 8, surface runoff was higher by 23.44% when the area shifted towards urbanization. Furthermore, urbanization resulted in 18.7% lower baseflow, but evapotranspiration greater by 1.94%. This confirmed the assumption that there is an inverse relationship between evapotranspiration and baseflow. On the other hand, the increase in forest cover enhanced the infiltration in the watershed as illustrated by lower surface runoff and higher baseflow. This result is consistent with the studies of Baker and Miller (2013) and Getachew and Melesse (2012) that showed how watersheds with increased forest cover tend to have better infiltration and good subsurface storage recharge and surface runoff delay, while those which experience a decrease in forest cover have more pronounced rainfall-runoff response.

With the current forest land in Saug Watershed, only 0.01% of the total area, an increase in forest land will have positive impacts on groundwater and recharge, which are essential for irrigation and water and power supply in low-lying areas. The increased baseflow due to increased forest land promises more water during dry season.

Conclusion

This study showed that the SWAT model can be used as a management tool for modeling the impacts of land use and climate changes in the study of watersheds, provided there is sufficient input data for calibration and simulation. The model showed agreement between observed and simulated data.

Based on the simulation results, changes in climate and land cover, including increased precipitation and conversion of range/brush land to forest, will affect the present hydrologic balance of a watershed. Given the current condition of the test watersheds, an increase in precipitation tends to significantly increase surface runoff, which can cause serious erosion, sedimentation of the reservoirs, depletion of soil nutrients, and even flooding in low-lying areas within the watershed. Furthermore, increase in forest cover decreases surface runoff, increases evapotranspiration, and decreases baseflow. The flux in baseflow is significant for the test watersheds as they provide water for irrigation and domestic use in the area.

The impacts of land cover and climate changes on hydrologic responses are non-uniform from one watershed to another. A sound watershed management scheme can have potential benefits to improve water availability and reduce flood-risks downstream.

Finally, the results of the study can serve as basis for other watersheds that have similar characteristics in predicting the effects of land cover and climate changes on the hydrologic behavior of the watershed.

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