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Application of SWAT Model to Assess Impact of Climate and Land Use Changes to Sedimentation in the Abuan Watershed, Philippines

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Abstract

This study uses the Soil and Water Assessment Tool (SWAT) to quantitatively assess the impact of climate change, urbanization and reforestation on the watershed hydrology and sedimentation in the Abuan Watershed. Results showed that the model adequately and realistically simulated hydrological processes of the watershed with Nash-Sutcliffe (NSE) of 0.7 and coefficient of determination (R2) of 0.78 which are above the threshold acceptable value of 0.5 and 0.6 respectively. The model adequately captured both the peaks and monthly temporal variation of stream flow.

Simulation of climate change using the 2050 climate change indices derived from PRECIS under the A1B medium-range scenario showed a likely increase in water yield and surface runoff in 2050 time slices as a result of the increase in annual rainfall in the river basin.

Application of the model on analysis of combined climate and land use changes indicated the positive impact of reforestation efforts in reducing rates of erosion in the watershed to water bodies. Result reveals that reforestation scenario will result to significant reduction of sediment yield of 3.8 tons per hectare of catchment during rainy months from July to December.

Keywords: abuan watershed, integrated watershed management, sediment, SWAT model, water resources

1 Introduction

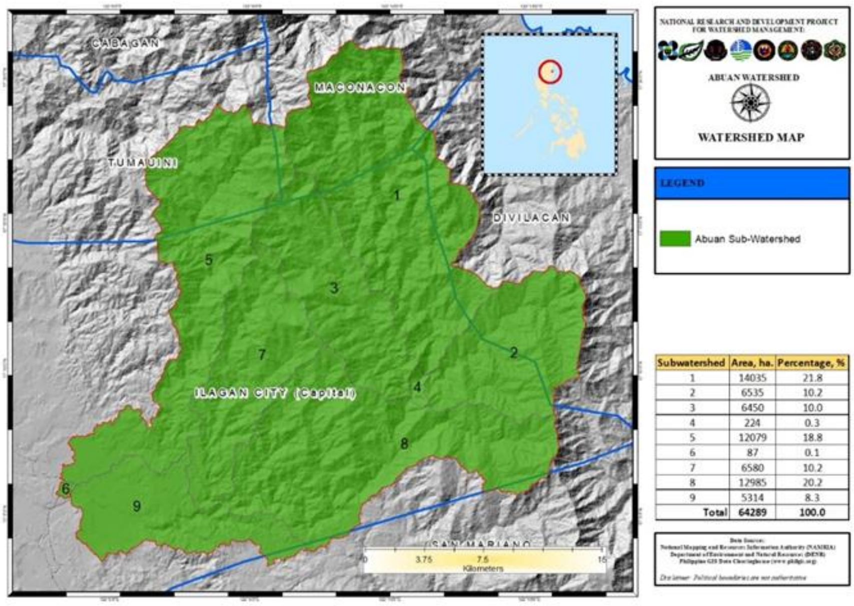
Watershed degradations throughout the years prompts the need for location specific interventions for proper watershed management and preservation. These degradations are due mostly of the increasing population in the watersheds who are highly dependent on its natural resources. Because of these, watersheds become more vulnerable to disasters such as typhoons, floods and droughts. Most watersheds are interconnected, which can affect each other in a domino effect. Anticipation of what can happen in a watershed has limited scientific bases especially when disasters happens. Over the year’s watershed models has been developed as decision support tool to prepare and reduce the adverse impacts of land degradation, shifting land uses and climate change.

The Soil and Water Assessment Tool (SWAT) model is a process-based watershed modeling platform introduced for USDA Agricultural Research Center. It is used to estimate the impact of various watershed management to soil erosion, runoff and soil nutrients across soil type, climate and topography (Arnold et. al., 2011). Furthermore, SWAT model has emerged as a useful tool for modeling water quantities and non-point source pollution (Arnold et al., 1998; Arnold and Fohrer, 2005) in various parts of the world. Many studies showed that SWAT has the capability to simulate watershed variables. Bulk of these studies reported that SWAT can accurately simulate streamflow (Briones et. al, 2016). Moreover, SWAT has the ability to estimate sediment yield and run-off (Alibuyog et. al, 2009).

2 Materials and Methods

Description of the study area

Abuan watershed is located at the Midwest of the province of Isabela (17°11’12”N, 122° 7’ 12”E). It has more than 63,790 hectares catchment. The watershed is divided into 26 sub basins. There are two major streams in the watershed, the Abuan and Binatacan rivers. The Bintacan river converges to the Abuan river just after the outlet of the watershed. The largest is sub watershed number 1, which measures 14,035 hectare is located at the northernmost part where water drains into the Bintacan river (Figure 1). Most areas of the watershed is classified as mountain soil. Clay loam and sandy loam soils characterizes the rolling and hilly areas, respectively. Further, the 2015 landuse map shows the upper catchments are mainly forest (89%) with more than 56,000 hectares. The lower sub catchments at nearly 3000 hectares are planted with agricultural crops (4.4%). These agricultural crops are mainly planted with corn. Kaingin or swiden farming that has total area 287.5 hectares are patching up in the middle part of the watershed. The communities are sporadically found at the lower sub catchments.



Subwatershed	Area, ha.	Percentage, %
1	14035	21.8
2	6535	10.2
3	6450	10.0
4	224	0.3
5	12079	18.8
6	87	0.1
7	6580	10.2
8	12985	20.2
9	5314	8.3
Total	64289	100.0

Figure 1. Abuan watershed map

The watershed receives an annual rainfall of 2124 mm during normal years. With less than 1810 mm annual rainfall, 1987, 1991, 1994, 1997 and 2004 were recorded as dry years. With rainfall greater than 2469 mm, there were 10 years recorded as wet years. The year 2011 had the highest rainfall amounting to 3054 mm. The mean monthly rainfall in the watershed shows an increasing trend that begins on the month of March until December with highest intensities during months of October until December. The driest months are February, March and April when variability in rainfall are highest.

Preparation of SWAT Model Inputs

Spatial data required by the model include a digital elevation model (DEM), land use map and soil map. The DEM, with a 10 m × 10 m resolution, was extracted from the ASTER Global DEM through the online data pool at the NASA Land Processes Distributed Active Archive Center (NASA LP DAAC, 2013). It was used for the sub-subwatershed delineation and slope map generation. The land use land map of the watershed is shown in Figure 2 was prepared by the National Research and Development Project for Watershed Management Project.

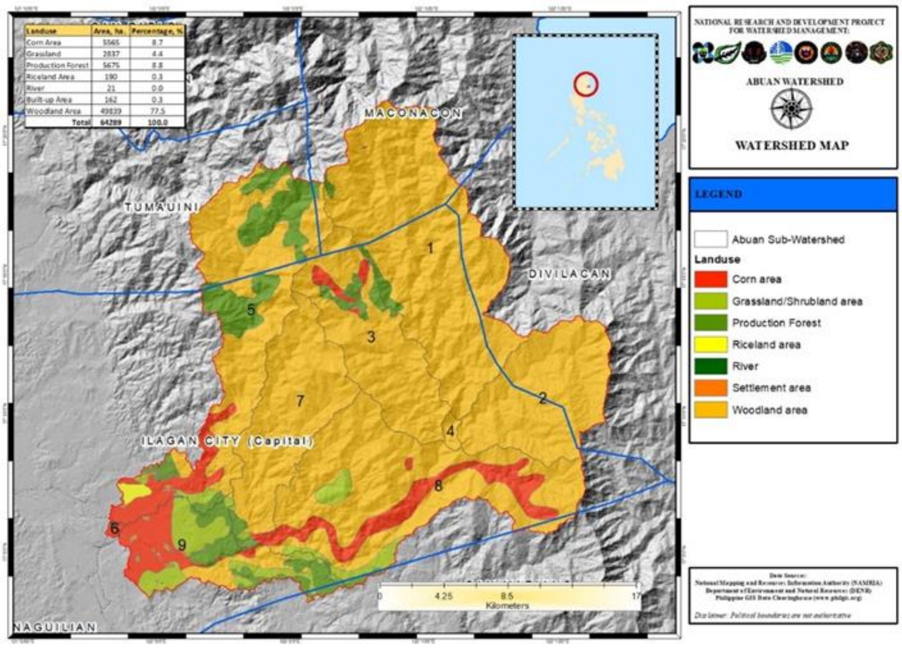


Figure 2. Landuse map of the study area

The soil attributes of these soils such as percent sand, silt, and clay, bulk density and infiltration rate among other parameters were extracted from the database and was encoded into the SWAT database. Likewise, time series of meteorological data such as rainfall, temperature, solar radiation, relative humidity, and wind speed were obtain from nearest weather station. Streamflow data were obtained from the Bureau of Research and Standards under the Department of Public Works and Highways (DPWH-BRS).

Evaluation of climate change impact on watershed hydrology

To understand the impact of increasing temperature and rainfall change on the hydrology of the basin, the calibrated SWAT model was used. The computed seasonal temperature and rainfall changes in 2050 under the A1B medium-range scenario were used to generate synthetic rainfall and temperature data for the period 2036-2065. The generated data were then used to run the calibrated SWAT model to simulate the water balance of basin. Table 1 shows the summary of the seasonal temperature increases and rainfall change under the A1B scenario generated by PAGASA using PRECIS (Providing Regional Climates for Impact Studies) into 2050 time frame.

Table 1. Seasonal temperature increases (oC) and rainfall change (%) in 2050 under the medium-range scenario (A1B) in the province of Isabela, Philippines

Time Frame	Temperature Increase (°C)				Rainfall Change (%)			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
2036 - 2065	2.0	2.1	1.6	1.9	25.1	-29.2	8.7	1.7

Model Calibration and Validation

Calibration was done using a long-term streamflow data gauged along Pinacanuan river for period 1992 to 2010 where the Abuan river is being drained. Part of the data (2008 to 2010) was used as validation period. Runoff data from the soil erosion monitoring plots were used to parameterize runoff process.

Model Application for Impact of Future Climate and Land Use Change

After successful calibration and validation of the Abuan SWAT model, it was used to assess the impacts of climate and land use change under future scenarios as follows:

Scenario 1 is a simulation of 2050 projected rainfall which is brought by climate change. Projected data were taken from PAGASA publications. It has been projected that during the rainy season, there will be an increase of rainfall by up to 25.1% and a decreased of 29.2% during the dry season. This would mean wetter days during wet season and drier days during dry season by the year 2050.

Scenario 2 is a depiction of agricultural (50%) and grassland (25%) areas conversion to settlements. This scenario is combined with 2050 projected rainfall changes. Agricultural areas with a total of 5,755 hectares and 2,837 hectares of grasslands will be inhabited in this scenario.

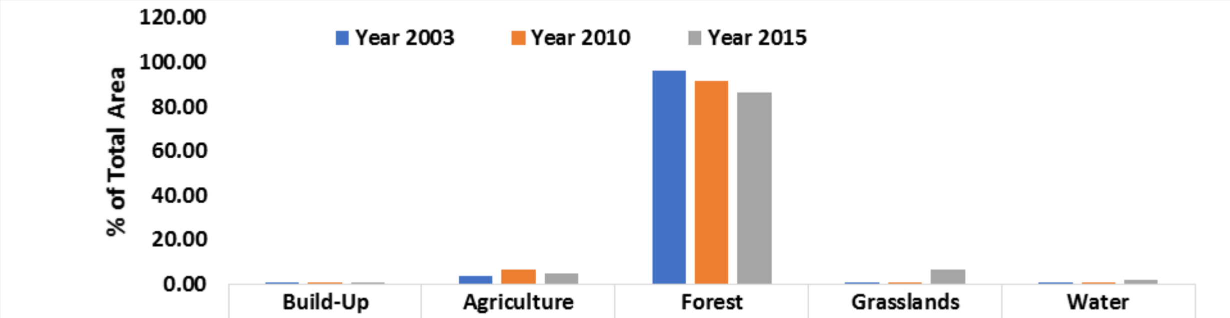
Scenario 3 is portrayal of reforestation with the projected 2050 rainfall values. Agricultural areas (50%) and grasslands (100%) are reforested. This translates to reforestation of 5,755 hectares of cultivated areas and 2,837 hectares of grasslands.

The impacts of these scenarios to the Abuan watershed hydrological processes were estimated and compared with the simulated baseline (1986-2016) values.

3 Results and Discussions

3.1 Analysis of land use change

Land use has prominently changed from years 2003 to 2010. Agriculture areas has almost doubled in 2015 or 2.5% cover increase while forest loss was recorded to almost 5000 hectares mainly due to conversion to urbanization, agriculture and grassland. A 100% increase in urbanization was also observed during the period and grasslands has increased by six-fold shown in Figure 3. One significant contributing factor is the uncontrolled “kaingin” practice and swidden agriculture.



	Build-Up	Agriculture	Forest	Grasslands	Water
Year 2003	0.12	3.53	96.03	0.03	0.29
Year 2010	0.16	6.86	91.75	0.35	0.87
Year 2015	0.22	5.09	86.25	6.66	1.78

Land Use Classification

Figure 3. Land Use Changes 2003, 2010 and 2015

The simulated streamflow in the gauging station were lumped into monthly totals and compared with the monthly measured streamflow. Results show that the simulated and measured streamflow matched well (Figure 4) with coefficient of determination, R2 of 0.78. The adequacy of the SWAT model to simulate the streamflow is also indicated by the positive NSE value of 0.99. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high streamflow. In fact, the model was able to capture both the high flows and low flows of the streamflow.

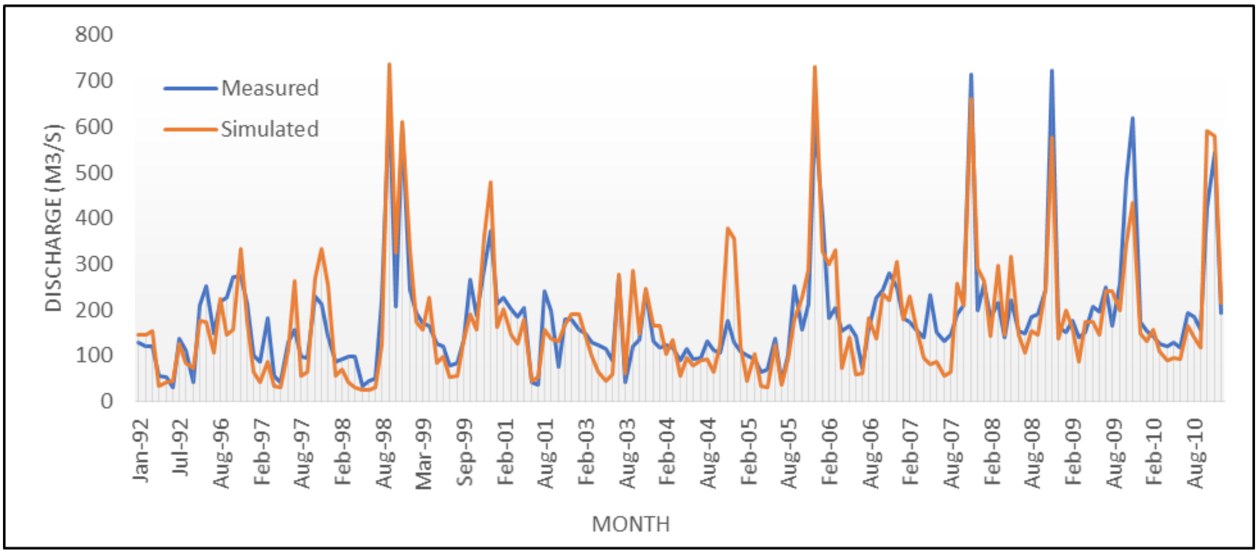


Figure 4. Monthly observed and simulated streamflow in the study area.

The results thus indicate that hydrologic processes in SWAT were modeled realistically and thus, can be extended to simulate other hydrologic process including various land use and climate change scenarios.

Simulation of sedimentation impacts of land use and climatic change scenarios

Impacts of land use change and rainfall increases were simulated at various increments as shown in Figure 5. Simulated soil erosion in 2050 would increase by 11.38% to 14.36% due to urbanization of cultivate areas and grasslands but with the reforestation of 50% cultivated areas and up to 100% grasslands, soil erosion will reduce by as much as 3.9 tons/ha/year.

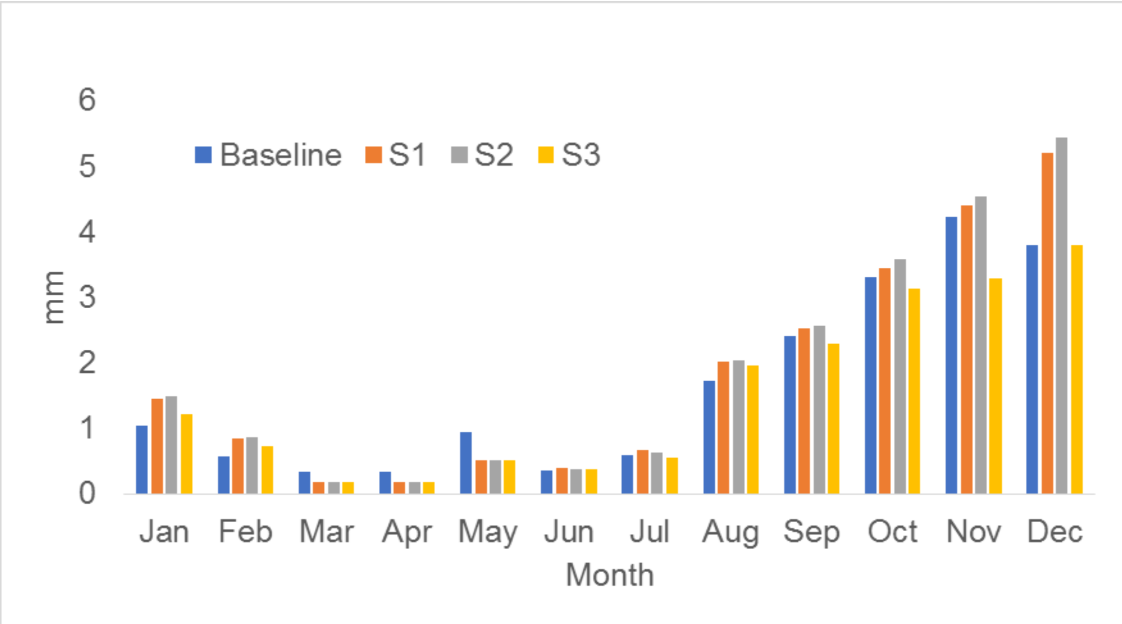


Figure 5. Simulated surface runoff, streamflow and sediment yield across scenarios.

4 Conclusions

A.The Soil and Water Assessment Tool (SWAT) model was successfully with Nash-Sutcliffe (NSE) of 0.7 and coefficient of determination (R2) of 0.78 which are above the threshold acceptable value of 0.5 and 0.6 respectively. The model adequately captured both the peaks and monthly temporal variation of stream flow.

B. Simulation of climate change using the 2050 climate change indices derived from PRECIS under the A1B medium-range scenario showed a likely increase in water yield and surface runoff in 2050 time slices as a result of the increase in annual rainfall in the river basin.

C. Simulation results revealed that reforestation efforts would significantly reduce the risks of flooding due to excessive runoff and would decrease soil erosion by up to 3.9 tons/ha/year.

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