SWAT MODEL FOR ASSESSMENT OF CLIMATE CHANGE AND LAND USE/LAND COVER CHANGE IMPACT ON PHILIPPINE SOIL LOSS AND EXPLORATION OF LAND COVER-BASED MITIGATION MEASURES: CASE OF CAGAYAN RIVER BASIN

Jeark Principe[1] and Ariel Blanco[2]

[1,2] Department of Geodetic Engineering, Melchor Hall, University of the Philippines Diliman, Quezon City, Philippines, Tel. +632-9818500, e-mail: jeark.principe@up.edu.ph [1], ariel.blanco@up.edu.ph [2]

Received Date: January 4, 2013

Abstract

As a climate hotspot, the Philippines is vulnerable to worst manifestations of climate change (CC) including severe soil loss rates, which are prevalent in the mountainous areas. Deforestation and land use/land cover (LULC) conversions may also aggravate the ill-effects of CC as forest areas are converted to built-up and vegetation types other than forest. This paper presents the application of Soil and Water Assessment Tool (SWAT) model integrated with Remote Sensing (RS), and Geographic Information System (GIS) to quantify the impact of CC and LULC change on Philippine soil loss rate. The model is applied in the country's largest river basin—the Cagayan River Basin (CRB). Remotely-sensed data such as the Landsat TM and ETM+ imageries and 90-m resolution Shuttle Radar Topography Mission-Digital Elevation Model (SRTM-DEM) were utilized to derive the LULC maps and DEM of the study area. Meanwhile, ArcGIS™ provided the platform for ArcSWAT interface of the SWAT model and for input, analysis, and display of spatial data. Evaluation of model performance showed that SWAT can realistically model flow and sediment discharge dynamics in the CRB as supported by satisfactory values of four statistical measures of model efficiency during model calibration and validation of mean daily river discharge and sediment yield. The calibrated model was rerun to incorporate projected variations in several climatic parameters (e.g., temperature and rainfall) considering the A1B SRES scenario and LULC change. The simulations incorporating CC and LULC change data have shown increases in soil loss rates for the CRB as high as 37% compared to the base scenario. Meanwhile, simulations which incorporate land cover-based mitigation measures have indicated successful reduction in soil loss rate by 33%.

Keywords: Climate change, GIS, Land use/land cover, Mitigation measures, Remote sensing, Sediment yield, Soil loss, SWAT model

Introduction

Sedimentation in river basins should be closely monitored due to its negative effects on the riverine and coastal biodiversity and the surrounding community residing in the area. In particular, sediments can reduce breeding habitats for fishes and their prey while stream turbidity is expected to increase due to suspended sediments that impair fish feeding [1]. Meanwhile, exacerbated flooding and bank erosion are expected to be the effects of high sedimentation and continuous constriction of the Cagayan River beds [2].

The Philippines is a climate hotspot and vulnerable to some of the worst manifestations of climate change [3]. The country's geographic and geologic setting has made it prone to natural disasters brought by the passage of tropical cyclones and occurrences of extreme or prolonged rainfall, strong earthquakes, volcanic eruptions and tsunamis and these hazards will be aggravated and the impact of geological events can be worsened by global warming [4].

To quantify effects of certain parameters, such us meteorological variables, on the hydrology and water quality aspects (including sedimentation) of a watershed, countries around the globe have employed different watershed models. It may even be difficult to think nowadays of solutions to an environmental or a water resources problem without some form of application of a watershed model as it have become a main tool in addressing a wide spectrum of environmental and water resources problems including water resources planning, development, design, operation and management [5].

The objective of the study is to quantify the impacts of climate change and LULC change on the soil loss rate of the Cagayan River basin by simulating sediment yield using the SWAT model. The study also aims to explore land cover-based mitigation measures, such as reforestation and afforestation of hilly, mountainous and riparian areas, to reduce sediment discharge.

Watershed Models and SWAT

Watershed Models

There are a wide range of watershed models that are utilized by different researches for watershed studies. Lim Suan [6] briefly described popular watershed models such as CREAMS, WEPP, SSARR and SWAT models. Moreover, Singh and Frevert [5] provided a detailed discussion on various watershed models and grouped them into streamflow, streamflow and water quality, urban watershed, agricultural watershed, and planning and management models. One of such models is the Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) Model, "a physically based, distributed parameter, structured grid, hydrologic model that simulates the hydrologic response of a watershed given hydrometeorological inputs" [7] and used for simulating diverse streamflow-producing processes [8]. GSSHA was applied by Johnson et. al [9] to simulate runoff from a tile drained Upper Auglaize watershed by modifying the existing model parameters. The artificial neural network (ANN) has also become an effective tool for modeling complex hydrological processes because in applying ANN models, one does not need to understand and define physical processes governing a system [10]. The performance of ANN model was compared against SWAT model in a study by Talebizadeh et. al [10] which revealed more accurate estimated low and medium values of sediment by the former while the latter showed better performance in estimating high values of sediment. These watershed models can be applied in the field of watershed science in the Philippines but can also be modified to suit local conditions [6].

The SWAT Model

The Soil and Water Assessment Tool (SWAT) model is a "river basin, or watershed, scale model developed to predict the effect of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time" [11]. The model's salient characteristics can be summarized as follows: physically based, a product of a series of modifications and integration of previous models developed by the USDA Agricultural Research Service, a continuous time model, not designated to simulate detailed single-event flood routing [11] and operates on a daily time step [12].

The SWAT 2005 version via the ArcSWAT interface for ArcGIS™ was used in this study. The interface automatically delineates the basin or watershed area and sub-watersheds using an input DEM. ArcSWAT further partitions each sub-watershed into areas called Hydrologic Response Units (HRUs) using unique combinations of land use, soil and slope as defined by the user. To predict surface runoff yield, the model uses a modified version of the SCS CN method [13] while erosion and sediment yield are estimated from each sub-watershed using the Modified Universal Soil Loss Equation (MUSLE) [14].

Application of SWAT in Other Countries

SWAT model has undergone extensive validation [11] and due to its versatility, has also been and continues to be used throughout the world in studying a wide range of phenomena [15].

In Japan, the model was used, after successful model calibration and validation, to model streamflow in the Hii river basin [16]. The study was conducted as their first step to water resources management and to add new studies to a relatively few studies available in Japan that analyses runoff and pollutant loads in their river systems. Meanwhile, SWAT model was used by Benaman et. al [17] to successfully model streamflow and sediment loading in the Cannonsville Reservoir basin—a New York City water supply watershed—in upstate New York. The said study presented the limitations of the model including its approach in snowmelt, sediment erosion and sediment transport.

The model was also utilized by Schoul and Abbaspour [18] for freshwater quantification in West Africa by modeling river discharges of Niger, Volta and Senegal rivers. Through the use of the SWAT model, Mishra et. al [19] have successfully selected priority subwatersheds where structure-based control must be built to effectively control sediment transport to downstream water resources of Banha watershed in Jharkhand, India. The model was also calibrated and validated by Wong et. al [20] in the Raisin River watershed in Ontario, Canada using five land cover scenarios to study the influence of patterns in terrestrial habitat to water quality and quantity of the watershed. Using SWAT, Duan et. al [21] have generated soil loss class map of a basin in Hebei province, northeast China to identify critical areas for erosion control.

The above mentioned application of SWAT in other regions of the world only shows how the model can be successfully used for various applications for watershed management and protection.

The Cagayan River Basin

The Cagayan River Basin (CRB) is located at the Northeastern portion of the Luzon island and is bounded by 15°52'N-18°23'N latitudes and 120°51'E-122°19'E longitudes (Figure 1). It is the largest river basin in the Philippines having a drainage area of approximately 27,700 km^2 covering nine provinces (Cagayan, Isabela, Nueva Vizcaya, Quirino, Mountain Province, Ifugao, Kalinga, Apayao and Aurora) [22].

The National Statistics Office reported more than 3.2 million people residing in the Cagayan Valley region where CRB is located and projected an increase of 9.5% by 2013 [23]. The region has no pronounced maximum rain period. It has a short dry period with a mean annual temperature that ranges from 23.6°C to 26.0°C and relative humidity at 75%-85% [24]. Rainfall varies from a mean annual precipitation of 1,000 mm at the Northern part and 3,000 mm in the Southern mountains [25].

Forest, vegetation, bare soil, built-up and water areas occupy about 42.3%, 30.1%, 24.1%, 2.3% and 1.2% the basin, respectively, using a 2009 land cover map generated in this study using satellite images. Utilizing the Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM, 90-m resolution), a slope map was generated classifying about half of the basin with relatively flat terrain, a third having slopes between 17-42% while the rest are with steep slopes (>42%). CRB is also bounded by three mountain ranges namely, Sierra Madre, Cordillera Central and Caraballo-Maparang in the East, West and South, respectively [26].

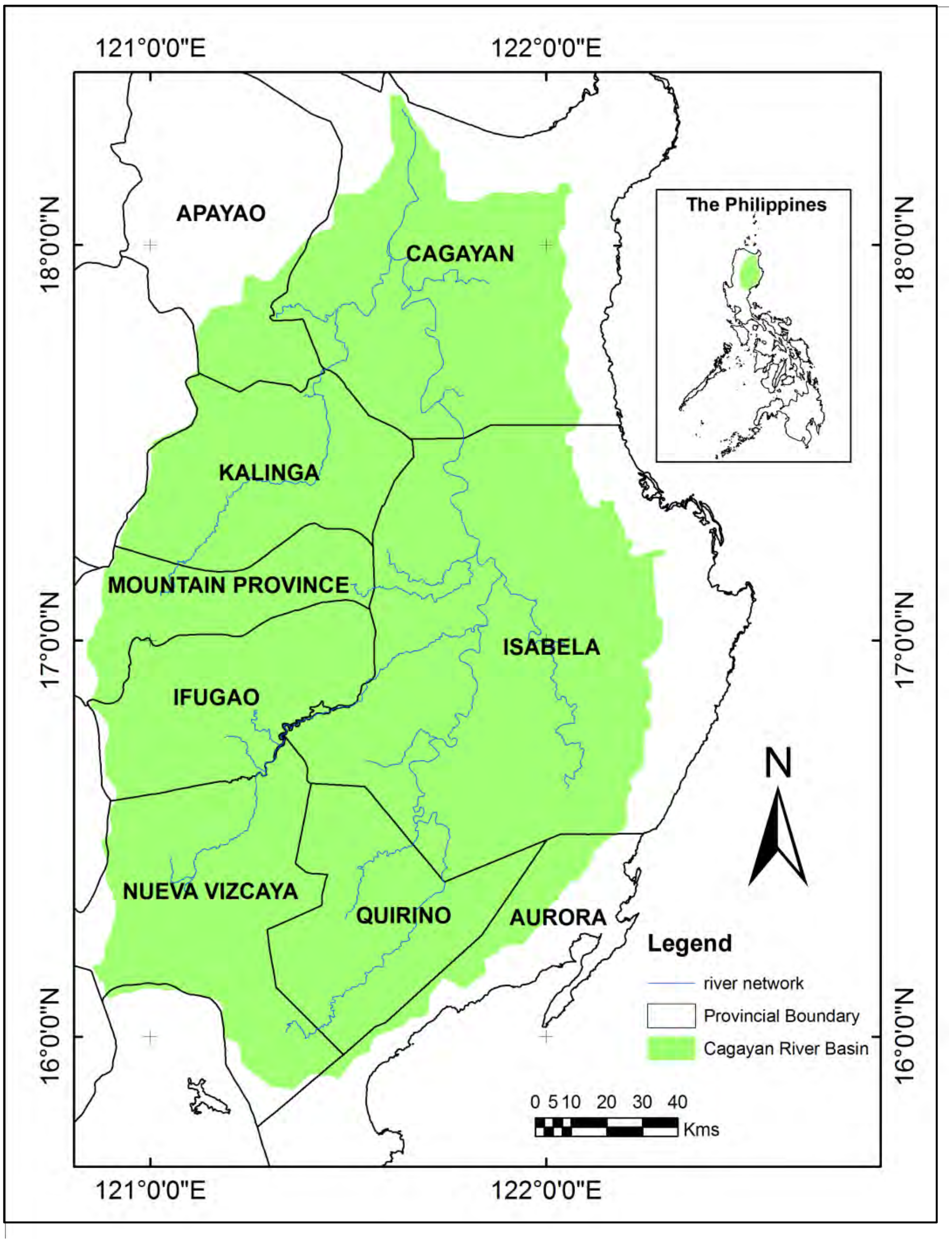


Figure 1. The cagayan river basin shown with the nine provinces it covers

Methodology

The methodology developed in the study is shown in Figure 2. Several spatial and non-spatial data are processed in preparation for their input to the SWAT model. Calibration and validation of the model is done using these pre-processed data. The initial run of the model has produced the first set of simulated soil loss rates, based on sediment yield, per sub-watershed (called base scenario, as inputs are still in their original form). For climate change and LULC change analysis, two land cover maps were processed for image differencing to compute for land cover class change rates and together with the climate change data, these were inputted to the model to modify LULC distributions and weather data. These modified inputs have produced another set of simulated soil loss rates incorporating CC and LULC change data. Finally, the land cover-based mitigation measures were also inputted to the model for another set of simulations of soil loss rates. Outputs from the three runs were then compared for final analysis.

Data Preparation and Input of Remotely-Sensed Data

SWAT Model requires high data input demand but can be expected to produce quality outputs after specifying basic input variables and their calibration [27]. The required ArcSWAT spatial datasets are the Digital Elevation Model (DEM) in ESRI GRID format while the LULC and soil datasets are in either ESRI GRID, shapefile or feature class format [28].

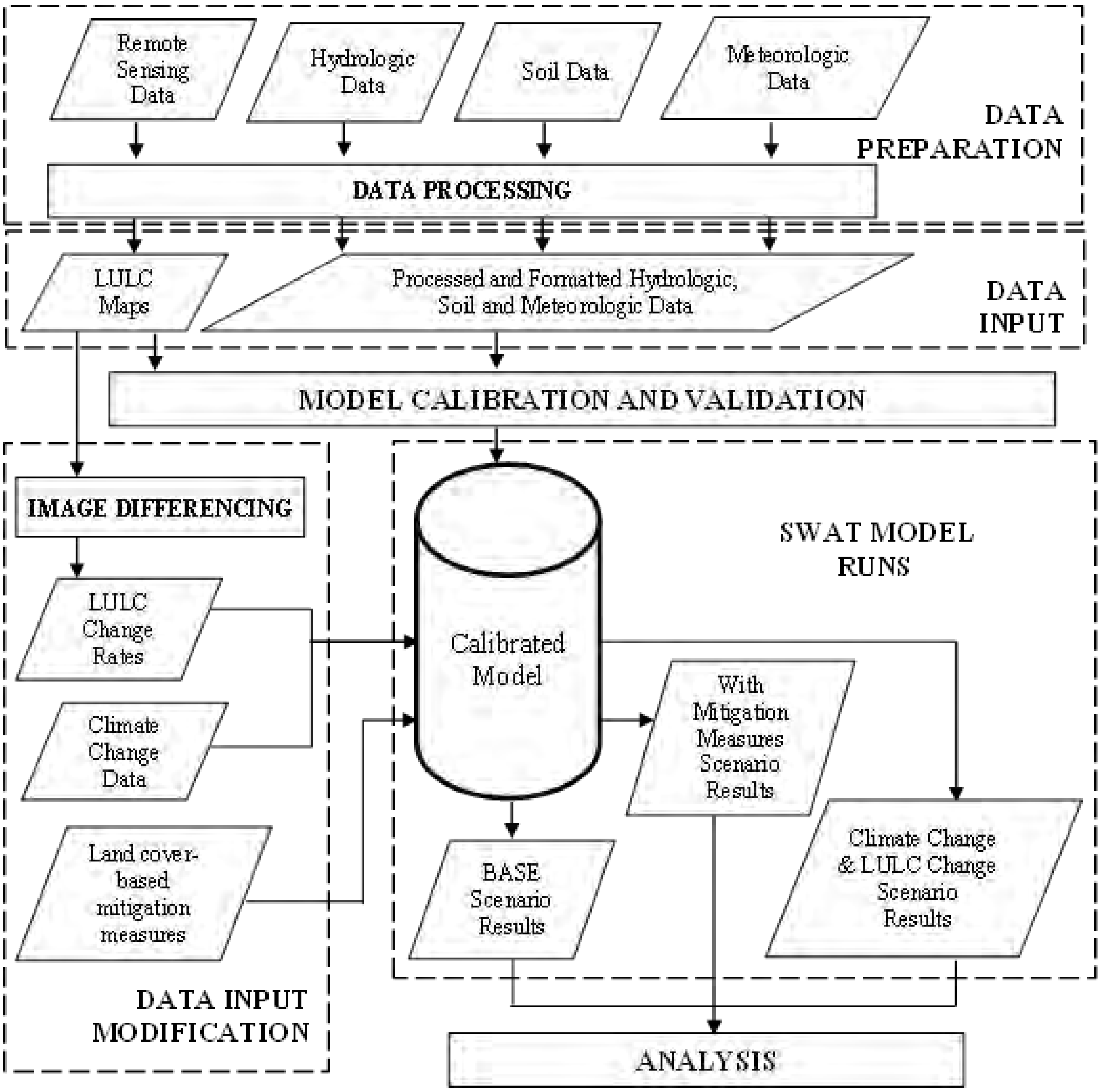


Figure 2. The general procedure developed in the study which includes data preparation, data input, model calibration and validation, SWAT model runs, data input modification and analysis of the results of each model run for different scenarios

Digital Elevation Model

The SRTM-DEM was used for the topographic data requirement of SWAT. SRTM data are products of processed raw radar signals spaced at different intervals at the Jet Propulsion Laboratory (JPL) [29]. The DEM used in the study was a 3 arc-second (approximately 90 m) medium resolution elevation data re-sampled using cubic convolution interpolation. The dataset was downloaded from the EarthExplorer website[1]. The DEM was used to generate percent slope values, to automatically delineate watershed boundary, define stream networks, and identify gage outlets. Figure 3 shows the boundary of the Cagayan River basin, the SRTM-DEM and the user-defined DEM mask to limit the processing of the source DEM within the approximated area of the Cagayan River Basin.

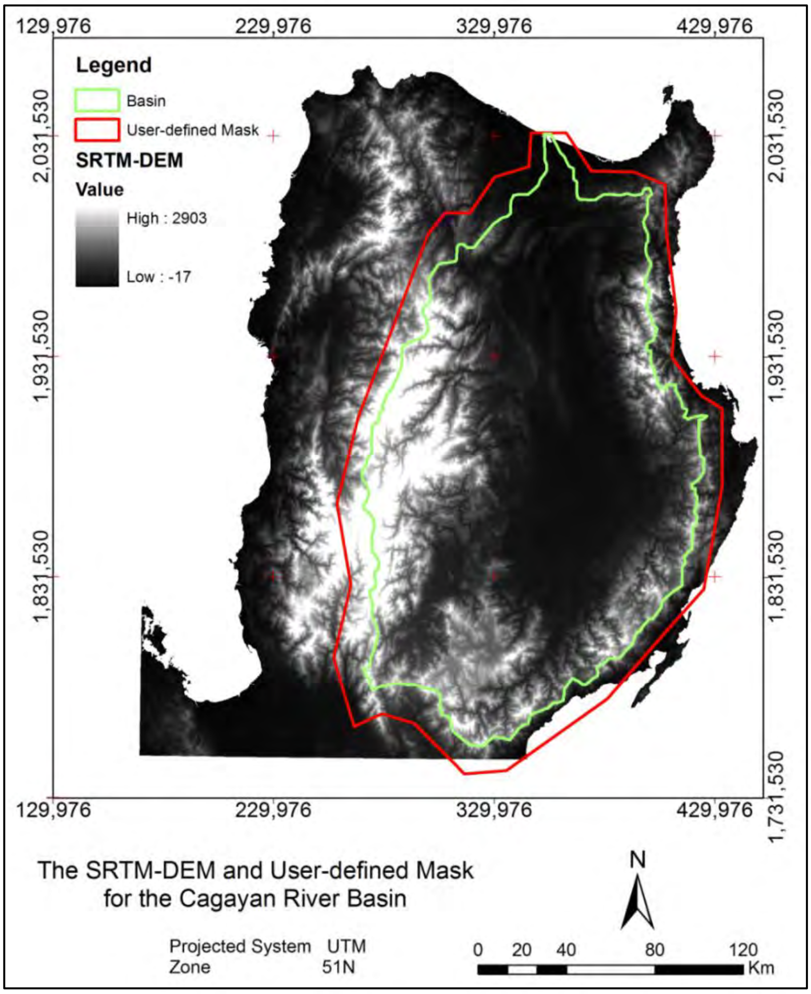


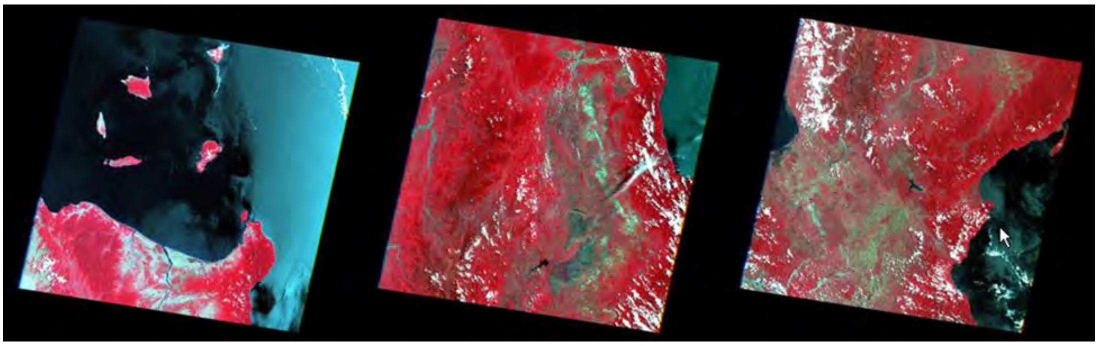
Figure 3. The SRTM-DEM coverage for the Cagayan river basin. It shows that a huge portion of the basin is flat at the center while areas with steep slopes are at the edges where mountain ranges are located. The user-defined DEM mask was used to limit the processing of the source DEM within the approximated coverage of the study area

Landsat Data for LULC Map and Change Rates

The Land Cover/Land Use (LULC) map was generated from a series of Landsat 7 TM and ETM+ images downloaded from the US Geological Survey Global Visualization Viewer

[1] URL: http://edcsns17.cr.usgs.gov/NewEarthExplorer

site[2] (USGS GLOVIS). The Cagayan River Basin is fully covered by three Landsat scenes within the coverage of path 116 and rows 47-49. Figure 4 shows a sample of these images dated 05-08-2003, 06-03-2001 and 05-18-2001 displayed in false color composite (bands 4-3-2 combination). All images were pre-processed for atmospheric correction prior to a cloud and cloud-shadow filling procedure. The Maximum Likelihood classifier was used to classify the image since it yielded the highest over-all accuracy and kappa coefficient as tested against five other classifiers (Parallelepiped, Minimum Distance, Mahalanobis Distance, ISODATA and K-Means). To produce the LULC maps, image classification was done on per image basis to minimize the possible error due to seasonal changes.



(a) (b) (c)

Figure 4. Sample Landsat images of the CRB shown in false color composite 432: (a) northern portion, (b) central portion, (c) southern portion of the CRB

Two LULC maps were generated from two sets of Landsat images, the information of which are summarized in Table 1. Images with different dates for the same scene will also make it possible to compute for land cover class change rates and perform cloud and cloud-shadow filling. The final classified images are shown in Figure 5 while the general land cover classes and corresponding SWAT LULC codes are presented in Table 2.

Table 1. Information on Landsat Images Used in the Study

Path	Row	SET 1		SET 2	
		Date	Cloud Cover (%)	Date	Cloud Cover (%)
116	47	May 08, 2003	1	Mar 05, 2009	14
		June 03, 2001	5	Mar 24, 2010	7
		June 22, 2002	12	Feb 04, 2010	7
		May 02, 2001	12	Feb 12, 2010	3
	48	June 03, 2001	8	Mar 05, 2009	7
		June 22, 2002	10	Mar 24, 2010	8
		May 08, 2003	11	Feb 04, 2010	7
		May 02, 2001	35	Feb 12, 2010	2
	49	May 18, 2001	13	Feb 04, 2010	7
		April 03, 2002	2	Mar 05, 2009	14
		May 08, 2003	9	Mar 24, 2010	7
		May 02, 2001	36	Feb 12, 2010	5

[2] http://glovis.usgs.gov

The Set 2 LULC map is subtracted from that of Set 1 to produce land cover change statistics using image differencing module in ENVI™ software. Referring to the said statistics in Table 3 and considering a period of 10 years (2001-2010), the land cover change rates per year are defined as follows:

- 4% and 1% of RNGE areas area converted to AGRL and URML, respectively
- 3% and 0.01% of FRST areas are converted to AGRL and URML, respectively

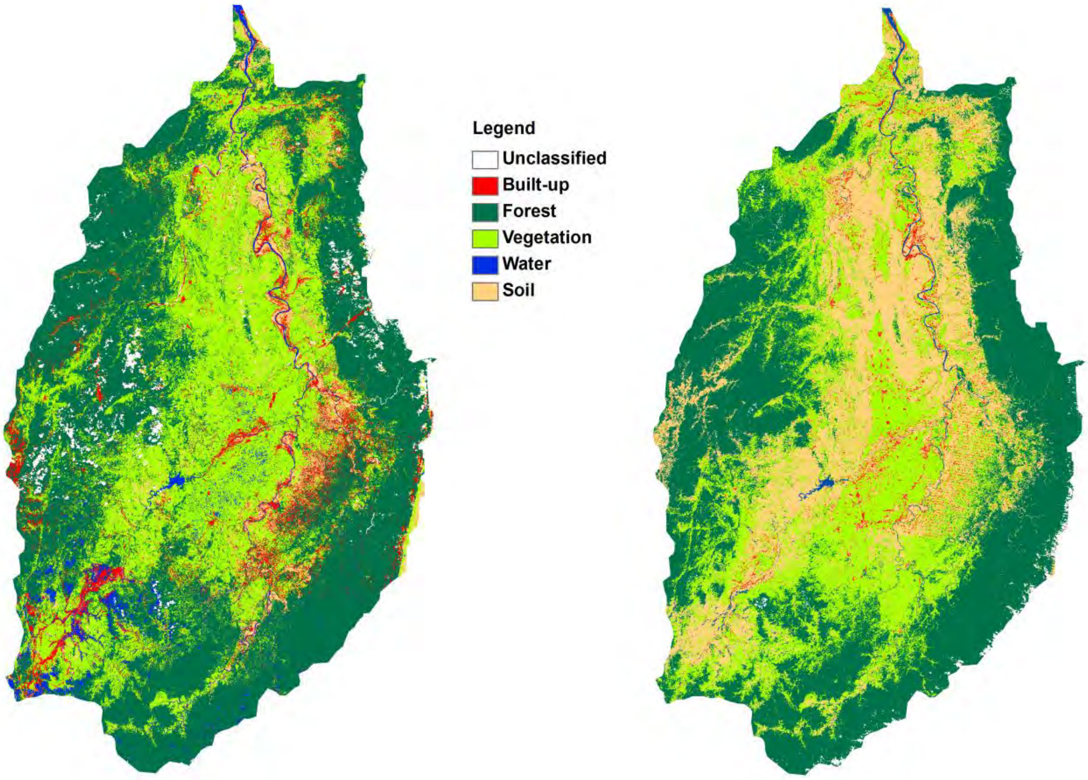


Figure 5. Land cover map of the CRB using maximum likelihood classifier to the mosaic of Set 1 (Left) and Set 2 (Right) images. An image difference from these two classified images will be used to compute for LULC change rates

Table 2. User-Defined and SWAT LULC Classes and their Description

USER-DEFINED LULC	SWAT LULC CODE	DESCRIPTION
Unclassified	AGRL	Agricultural Land Generic
Built-up	URML	Residential-Medium to Low Density
Bare soil	RNGE	Range-Grasses
Water	WATR	Water
Vegetation	AGRR	Agricultural-Row Crops
Forest	FRST	Forest-Mixed

Data Preparation and Input of Other Spatial and Non-spatial Data

Soil Data

The soil layer was generated from the Pit Profile Descriptions (PPD), Laboratory Analysis (LA) and Auger Boring Descriptions (ABD) of Cagayan, Isabela and Nueva Vizcaya provinces from the Department of Agriculture Bureau of Soils and Water Management (DA-BSWM). There are fourteen parameters in per soil layer that were derived from the available soil data from BSWM. For a detailed discussion on how these parameters were derived, the reader is referred to the work of Principe [30] and the SWAT model's theoretical documentation [11].

Table 3. Change Statistics for the Study Area

		Initial State					
		URML	**AGRL**	**RNGE**	**AGRR**	**FRST**	**WATR**
Final State	**URML**	10.65	0.01	6.27	3.57	0.53	0.75
	AGRL	0.14	96.46	0.66	0.16	0.59	1.30
	RNGE	54.72	0.38	43.97	45.85	5.32	17.95
	AGRR	19.19	0.30	33.98	44.70	20.30	29.37
	FRST	10.09	2.80	13.91	5.02	73.07	26.23
	WATR	5.21	0.05	1.21	0.70	0.19	24.40
	Image Difference	93.204	-2.763	151.262	-12.886	-15.961	-55.434

Weather Data

Three main weather stations are located in Cagayan and Isabela provinces. These stations have daily and monthly rainfall, humidity and temperature (minimum and maximum) data obtained from the PAGASA[3]. For a more localized account of precipitation patterns, three additional PAGASA rainfall stations located in Tabuk, Bangued and Baguio City were also used. Moreover, two additional Weather Underground®[4] precipitation data from stations in the Aurora province were also used. Hence, a total of eight weather stations, which are shown in Figure 6, were used in the study.

Climate Change Data

Data for climate change scenario A1B SRES[5] were extracted from PAGASA's run of the Providing Regional Climate for Impact Studies (PRECIS) model which generated projected changes in mean seasonal temperature (^{o}C) and rainfall (%) [31]. The sample graphical representation of these climatic parameter projections for Dec-Jan-Feb season is shown in Figure 7. To minimize significant biases in the model control simulations, the input used in the climate model is an observed climate (i.e., observed precipitation, temperature, etc.) with the required future climate information created by combining changes derived from model simulations of the present and future climate with the observed "baseline" climate. Moreover, in creating regional climate scenarios from PRECIS, many variables are included in the validation of the model to determine reasons for any biases identified [32]. PAGASA used the period 1971-2000 for the baseline climate.

River Discharge and Sediment Data

The SWAT model was calibrated and validated for flow and sediment using data obtained at the Bureau of Research and Standards (BRS) station located in Bangag, Lal-lo, Cagayan (Figure 6). This station was selected due to data availability and its proximity to the main

[3]Philippine Atmospheric, Geophysical and Astronomical Services Administration
[4] http://www.wunderground.com
[5] Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change (IPCC)

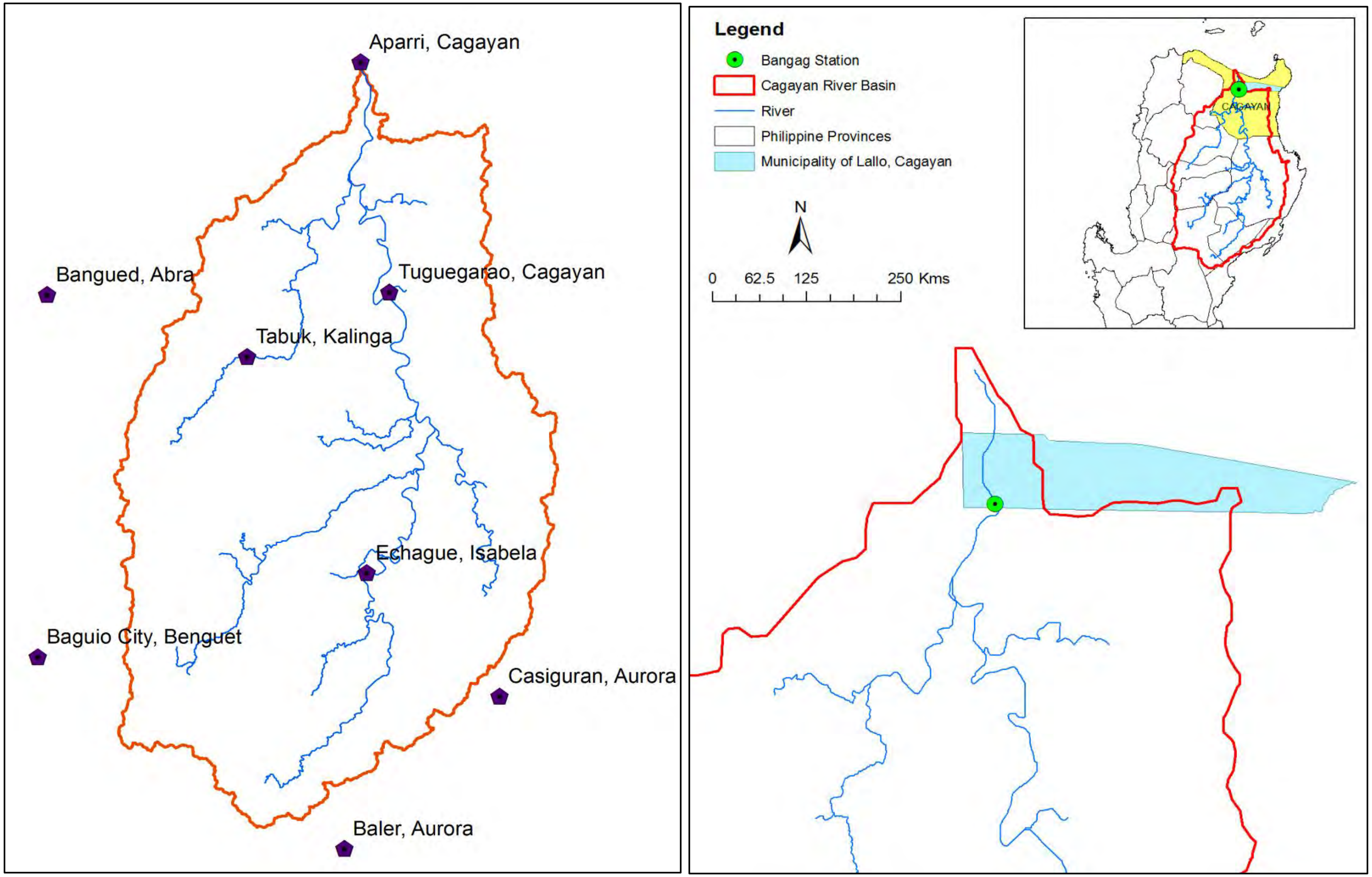
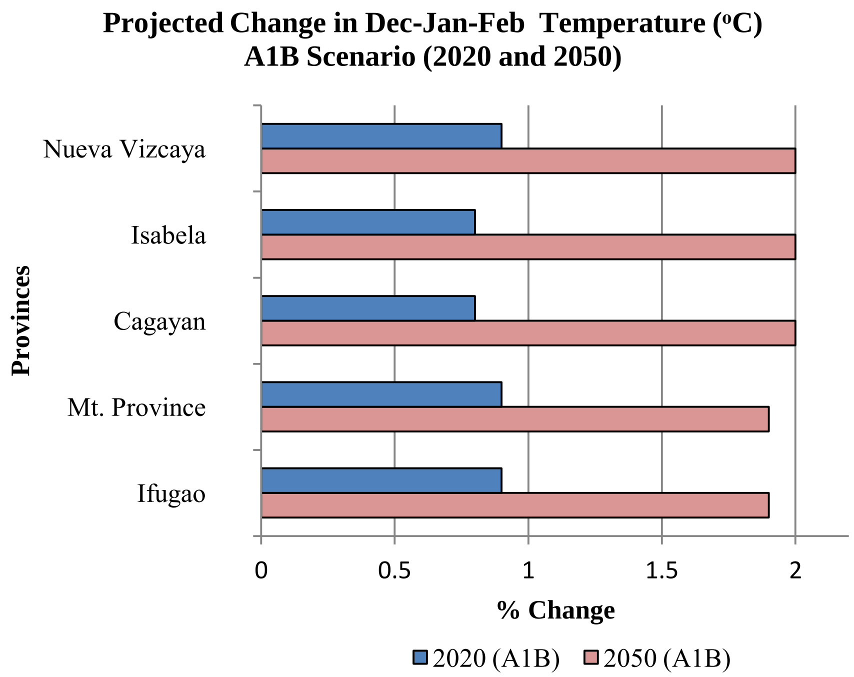


Figure 6. Weather stations in CRB (Left) and Bangag station (for water and sediment discharge monitoring) in Lal-lo, Cagayan (Right)



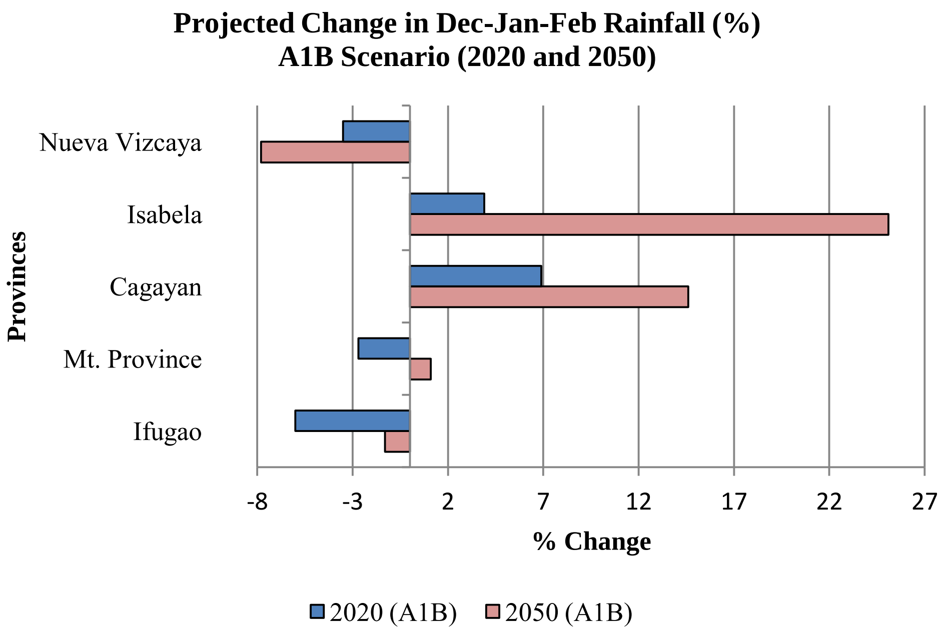


Figure 7. Projected changes in the December-January-February seasonal mean temperature and rainfall

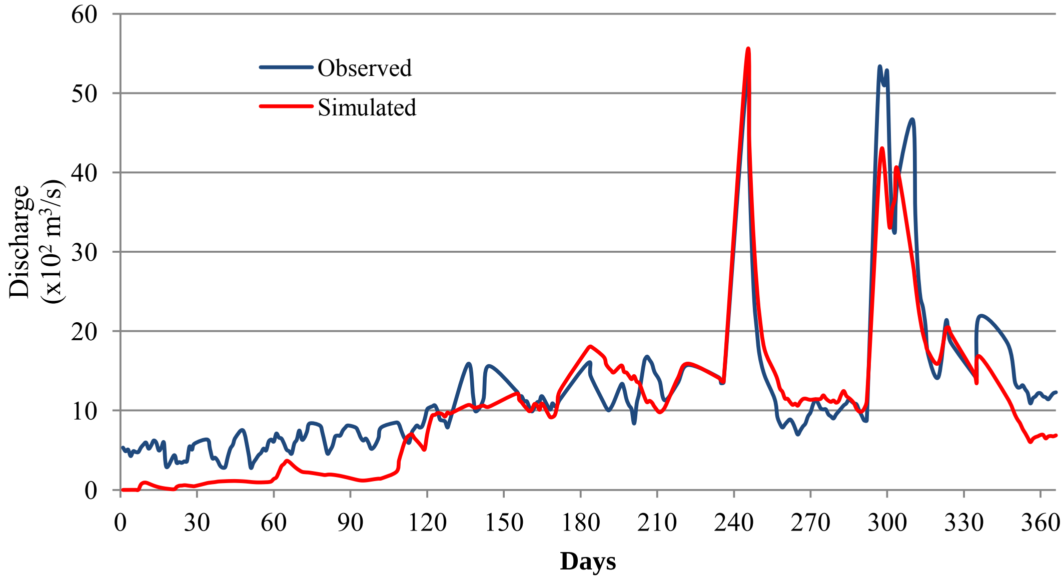
Table 4. Available Flow and Sediment Data for Bangag Station

Variable	Units		Calibration		Validation	
	Original	**Model Input**	**Period**	**Time Step**	**Period**	**Time Step**
Flow	li/s	m^3/s	1984	Daily	1985-1986	Daily
Sediment	ppm	ton/day	2002-2005	Monthly	2006-2007	Monthly

outlet of the basin. River discharge or streamflow and sediment data for this station were obtained from the BRS [24] the details of which are shown in Table 4. For model calibration, the 1984 daily stream flow (in liters/sec) data and 2002-2005 monthly sediment (in ppm) data were used. Meanwhile, the 1985-1986 daily stream flow data and 2006-2007 monthly sediment data were used for model validation. The original units of discharge and sediment data were converted to m^3/s and metric tons/day, respectively, as required by ArcSWAT for model input.

Model Calibration and Validation

The study used the automatic calibration technique in ArcSWAT and was later fine-tuned by manual calibration. Model validation was done by rerunning the validated model for a separate time period (Table 4) to see if the model is indeed appropriate for the study basin. Figure 8 and Figure 9 show plots of the simulated against the observed discharge and sediment values during model calibration and validation stages.



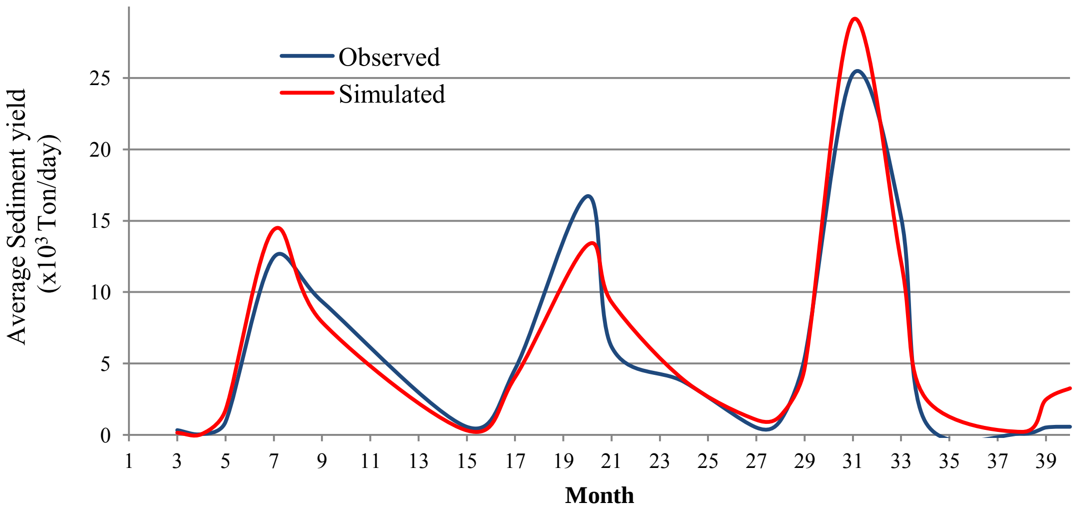
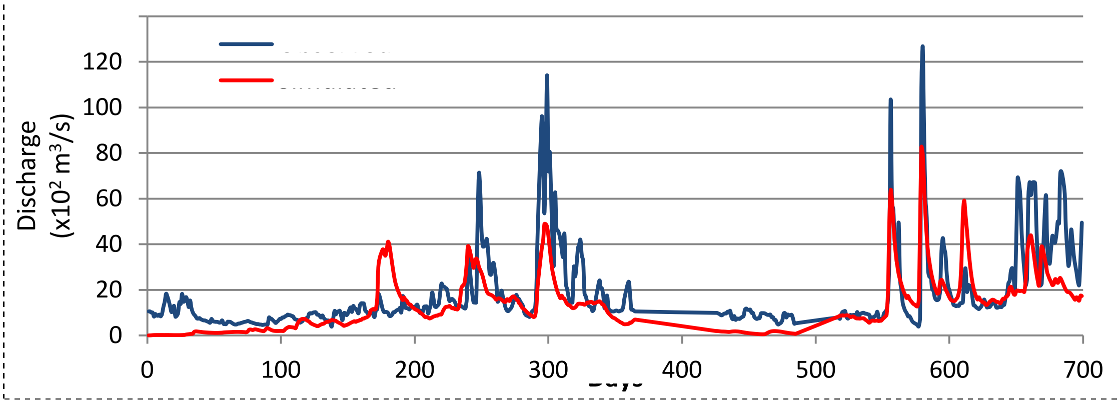


Figure 8. Observed and simulated discharge for year 1984 (above) and sediment for the period 2002-2005 (below) during model calibration



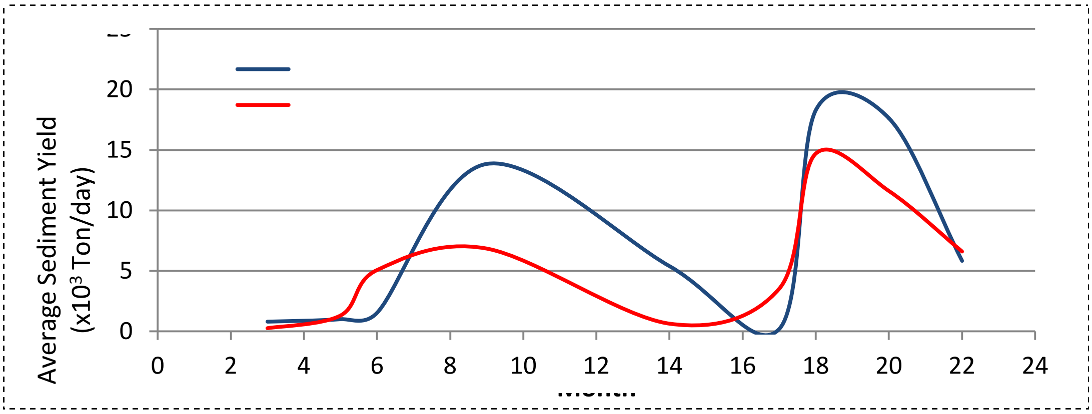


Figure 9. Observed and simulated discharge for the period 1985-1986 (above) and sediment for the period 2006-2007 (below) during model validation

Scenarios and SWAT Model Reruns

The calibrated model was rerun for three scenarios: (1) base scenario using original input data; (2) climate change and LULC change scenario where projected changes in mean seasonal climatic parameters and LULC change rates are inputted; and (3) land-cover based mitigation measures were reflected in the data with LULC change and climate change scenarios.

Assigning HRUs for Land cover-based Mitigation Measures

The last scenario explores proposed land cover changes that can potentially mitigate the impacts of climate change on soil loss rates in the Cagayan River Basin and eventually mitigate its adverse downstream effects. These land cover-based mitigating measures include riparian reforestation and afforestation of hilly and mountainous areas.

To model riparian reforestation, a buffer zone of 20 m was created from the river's reach (LULC is WATR). This buffer distance is the width of the strip of land to be established along the edge of normal high waterline rivers and streams with channels of at least five meters (5m) wide as prescribed by DAO No. 13 [33]. Areas covered by this buffer zone are shown in Figure 10. It is should be noted that there are some areas within the proximity of the river reach generated by SWAT that were not identified as HRUs for reforestation. The reason was that the reach generated by the model was based on the input DEM which is not affected by seasonal changes. The study created buffer zones for WATR areas which are greatly affected by seasonal variations and includes 'wet' areas and the river itself. Therefore, no HRUs were considered for reforestation near the river's reach that is intermittent. The percent change is equal to the percent area of the original

HRU that was covered by the buffer zone. This fractional area of the original HRU is added to the existing forest within the sub-watershed.

To model afforestation, areas with slopes greater than 42%–the lower limit of the slope class with the highest slope grades for the study area—were completely converted to forest cover. It should be noted that these areas for afforestation as shown in Figure 10 do not contain any built-up areas (URML). Thus, no restriction on land use conversion is expected.

Results and Discussion

Evaluation of Model Performance

Plots of the observed and simulated flow (Figures 8 and 9) indicate a better SWAT model simulation in high flows than in low flows which was also reported by Geza and McCray [34] in their SWAT application to the Turkey Creek watershed in Colorado, USA. Meanwhile, sediments are poorly simulated for high-flow events (Figures 8 and 9). The same result of sediment modeling in SWAT was observed by Alibuyog et. al [35] in their study of the selected Manupali River sub-watersheds in the Philippines. This observation was attributed to high deposition of sediments as they travel along the channel and channel erosion, especially during high flows, and other factors which the present model did not adequately capture [35].

The performance of the model was evaluated using four quantitative statistics as recommended and used by Moriasi et. al [34] and Duan et. al [21]. These statistics are the Nash-Sutcliffe efficiency (NSE), percent bias (PBIAS), ratio of the root mean square error to the standard deviation of measured data (RSR) and the coefficient of determination (R^2). NSE indicates how well the plot of observed versus simulated values fits the 1:1 line [35], PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts [36], RSR is the ratio of the Root Mean Square Error and the standard deviation of measured data (RMSE) [34] and R^2 is an indicator of relationship strength between the observed and simulated values [35]. In general, model simulation can be judged as satisfactory if NSE>0.40 and R^2>0.5 [21], and if RSR≤0.70, PBIAS ±25% for streamflow and PBIAS ±55% for sediment [34].

Table 5 and Table 6 reports that the model performed satisfactory for both calibration and validation stage except for monthly flow validation where RSR>0.70. This signifies a highly dynamic river discharges occurring in a daily basis—a perfect condition for watershed modeling in SWAT because the model runs in a daily time-step.

Table 5. Model Performance during Calibration

Variable	Calibration					
	Period	**Time Step**	**NSE**	**R^2**	**RSR**	**PBIAS**
Flow	1984	Daily	0.89	0.74	0.34	17.64
		Monthly	0.47	0.83	0.73	17.75
Sediment	2002-2005	Monthly	0.96	0.93	0.20	-7.30
		Annual	0.99	0.97	0.11	-12.31

Table 6. Model Performance during Validation

Variable	Calibration					
	Period	Time Step	NSE	R^2	RSR	PBIAS
Flow	1985-1986	Daily	0.62	0.58	0.61	23.22
		Monthly	0.43	0.64	0.75	32.45
Sediment	2006-2007	Monthly	0.67	0.76	0.57	21.68
		Annual	0.62	1.00	0.62	21.68

Results of SWAT Model Runs

The generated sediment yields for the three scenarios are discussed in the succeeding sections. These simulations were done on a yearly basis using the model calibration and validation periods for sediment (i.e., 2002-2007). The results from these simulations are averaged to get the mean annual sediment yield in ton per hectare per year (t ha^{-1} yr^{-1}). For each case, erosion rates in terms of the simulated sediment yield for each sub-watershed is classified as very slight, slight, moderate or severe using user-defined range of values.

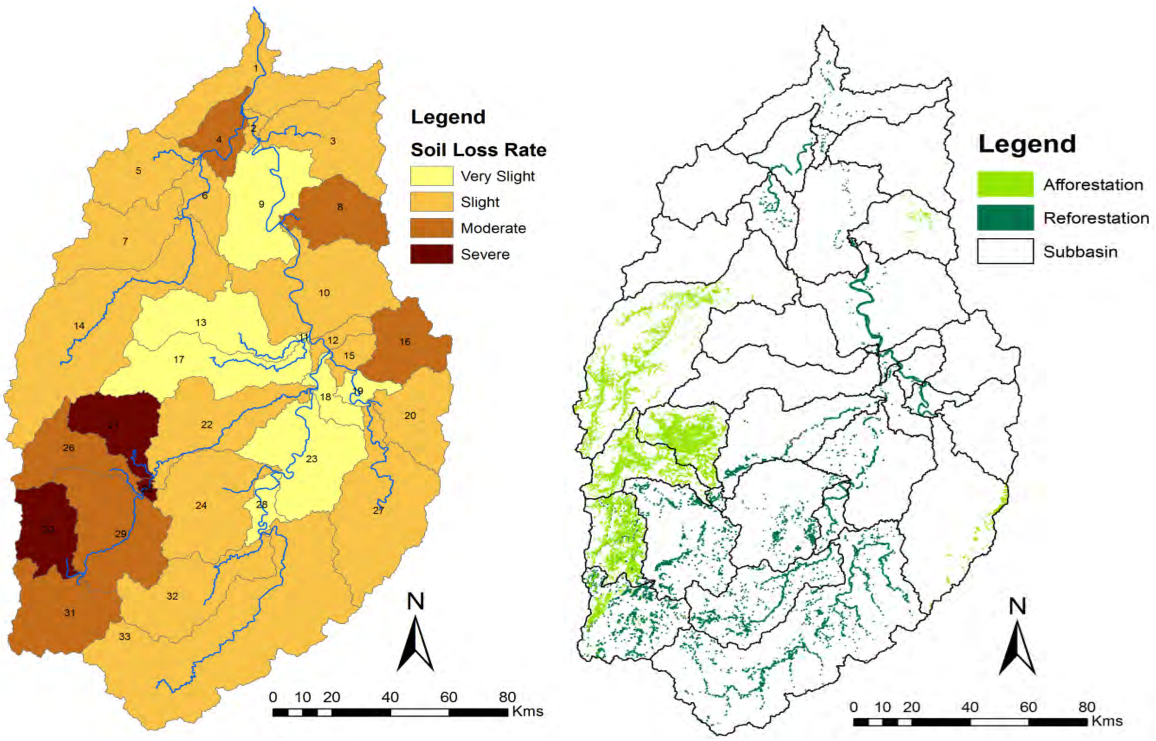


Figure 10. Soil loss map of the CRB under the base scenario (Left); HRUs within the Cagayan River Basin where mitigation measures (Right)

Base Scenario

Under this scenario, the calibrated model was rerun using the original dataset. As previously stated, sediment yield computation was done per sub-watershed. Table 7 presents the user-defined range of soil loss rate in tons per hectare per year and the corresponding sub-watershed numbers and percent of the whole basin under each soil loss class. The simulated maximum sub-watershed soil loss value of 12.05 t ha^{-1} yr^{-1} was beyond the upper limit of tolerable soil loss (11.2 t ha^{-1} yr^{-1}) according to Hudson [37] as cited by Alibuyog et. al [38]. The sediment yield for the Cagayan River Basin under this scenario is 114.79 t ha^{-1} yr^{-1} which is within the range of average erosion rate of 56.41 t ha^{-1}

yr^{-1} to 128.5 t ha^{-1} yr^{-1} reported by FAO [39] as cited by Asio et. al [40]. Figure 10 shows the spatial distribution of soil loss classes for the whole basin.

Table 7. Soil Loss Classes used in the Study and Percent Area of the Basin Covered by each Class under the Base Scenario

Soil Loss Class	Soil Loss Rate (t ha^{-1} yr^{-1})	Sub-watershed	Percent Area of the Basin (%)
Very Slight	<1.52	9, 11, 13, 17, 18, 19, 23, 28	17.42
Slight	1.52-4.13	1, 2, 3, 5, 6, 7, 10, 12, 14, 15, 20, 22, 24, 27, 32, 33	61.79
Moderate	4.14-8.79	4, 8, 16, 26, 29, 31	16.20
Severe	>8.79	21, 25, 30	4.59

Climate Change and LULC Change Scenario

Climate change data are incorporated in the model by inputting the projected mean seasonal change in rainfall and temperature for each sub-watershed. After manipulating the sub-watershed parameters for climate change analysis (RFINC and TMPINC), the calibrated model was rerun for A1B scenario under two time slices centered at year 2020 and 2050. A1B scenario has been the focus of climate change model inter-comparison studies according to IPCC [41]. Meanwhile, each derived LULC change rates were used to modify HRU files (with file extension *.hru) to model such predicted changes in land cover distribution.

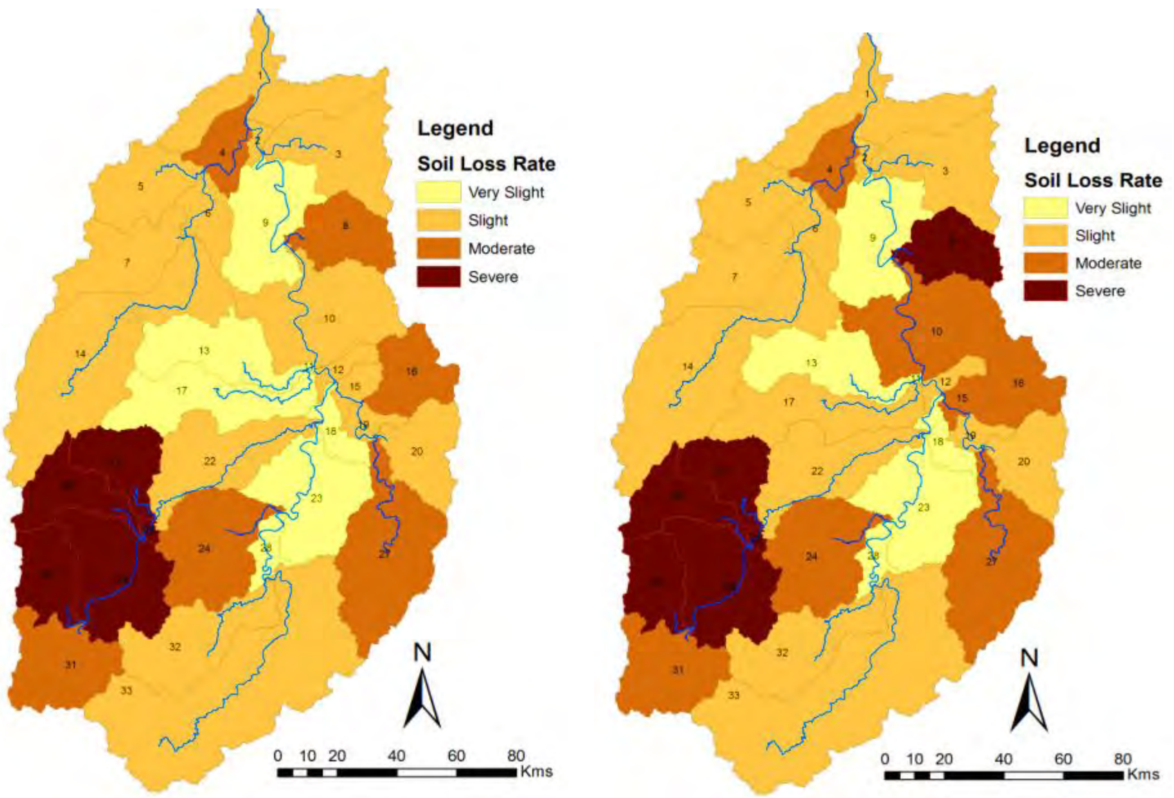


Figure 11. Soil loss map of the cagayan river basin considering the combined effects of climate change and land use/land cover change under two different time-slices centered at year 2020 (Left) and 2050 (Right)

Figure 11 shows the resulting soil loss maps for this scenario. It can be noted that the combined effects of climate change and LULC change (Figure 11) has produced a greater number of sub-watersheds experiencing severe soil loss rate compared to the base scenario (Figure 10).

Scenario Incorporating Mitigation Measures

This last scenario incorporates land cover-based mitigation measures to the second scenario to look at its effectiveness in mitigating the combined ill-effects of climate change and LULC change on soil loss. Figure 12 shows how riparian reforestation and afforestation of hilly and mountainous areas have reduced the intensity of soil loss rate in the Cagayan river basin by reducing the amount of sediment yield generated. Meanwhile, maps in Figure 13 show sub-watersheds with areas where severe to moderate soil loss rate classes occurred are effectively converted to moderate to very slight classes.

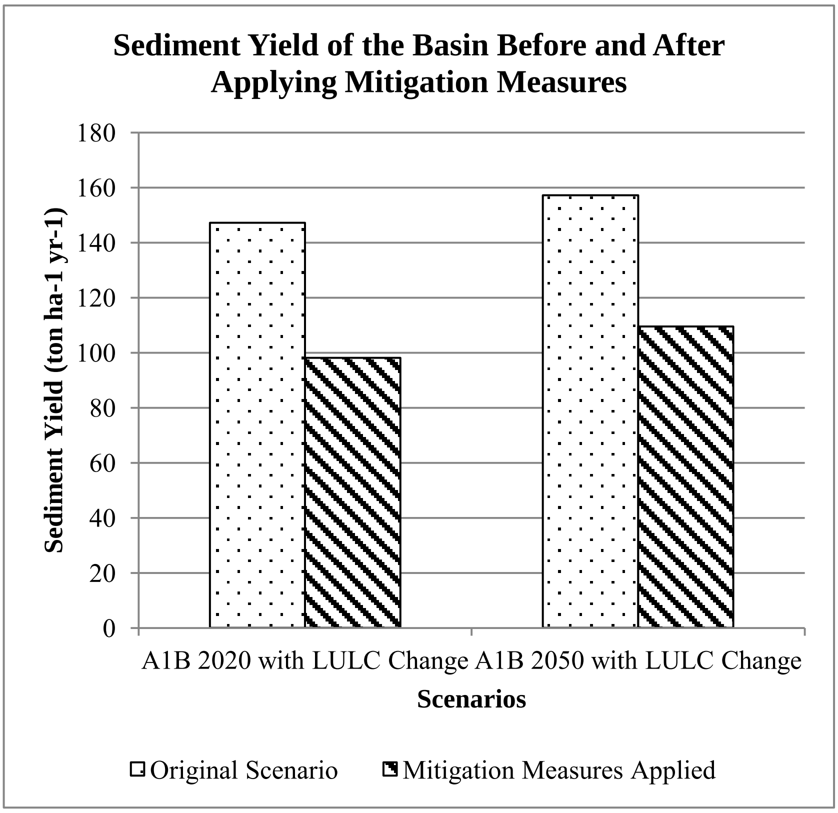


Figure 12. Sediment yield of the basin before and after applying mitigation measures

Conclusions

The study has demonstrated the application of SWAT model integrated with Remote Sensing and GIS to simulate watershed variables such as the sediment yield of a large river basin for soil loss analysis. Analysis made in this study indicated that SWAT models high flows better than low flows. On the other hand, sediments were poorly simulated for high-flow events. This is attributable to high sediment deposition. Nevertheless, the study has validated the applicability of the model in simulating the flow and sediment discharge dynamics of the Cagayan river basin based on the satisfactory values of the statistical measures of model efficiency. Through this approach, the adverse impacts of climate change and LULC change as well as the potential land cover interventions were evaluated.

It has been shown that if the current rate of land use/land cover change and the projected changes in the climate regime would persist, the sediment yield of the Cagayan river basin will approximately increase by as high as 37% (A1B 2050 with LULC change scenario). Meanwhile, the application of the proposed mitigation measures can significantly decrease soil erosion rates by 33% and 30% for A1B 2020 and 2050 with LULC change scenarios, respectively, thereby converting the sub-watersheds with severe soil loss rate to very slight and moderate classes.

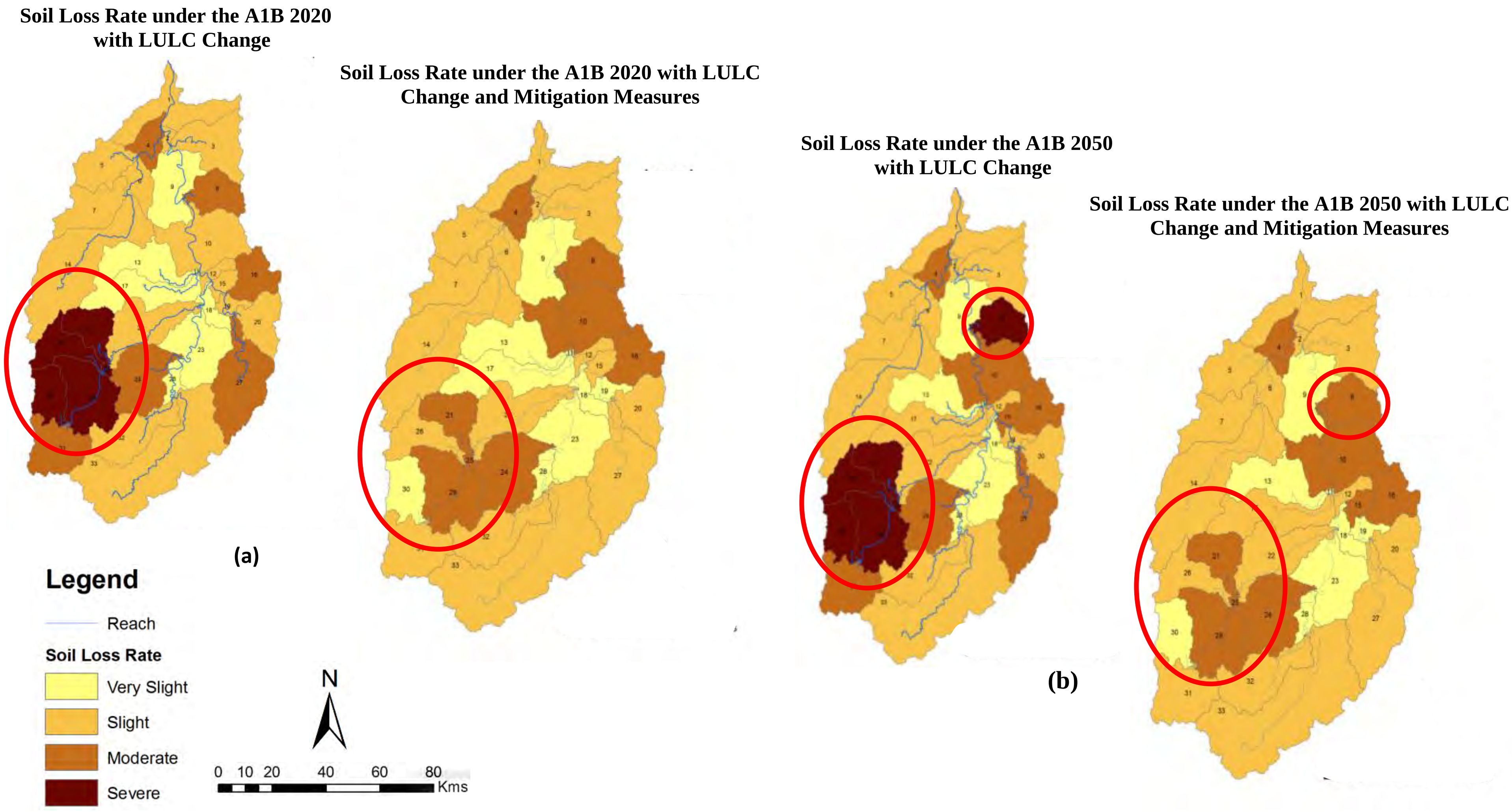


Figure 13. Soil loss maps before (left images) and after (right images) applying land cover based mitigation measure in scenarios with climate change scenarios (a) A1B2020 and (b) A1B2050 with LULC change. Areas in red circles are where severe to moderate loss rates conversions have occurred

Acknowledgement

The authors would wish to thank the support of the Philippine Department of Science and Technology through the Philippine Council for Industry, Energy and Emerging Technology Research and Development (PCIEERD) and the assistance of various government agencies such as the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), the Bureau of Research and Standards (BRS) of the Department of Public Works and Highways (DPWH) and the Bureau of Soils and Water Management (BSWM) of the Department of Agriculture (DA).

References

[1] J.L. Meyer, A.B. Sutherland, K. Barnes, D. Walters, and B.J. Freeman, "A scientific basis for erosion and sedimentation standards in the Blue Ridge physiographic province," In: K.J. Hatcher, ed., *Proceedings of the 1999 Georgia Water Resources Conference*, Athens, Georgia, United States, pp. 321-324, 1999.

[2] Philippine Information Agency News Center, "Study Shows Cagayan River Silted Parts Need Immediate Dredging," *Philippine Information Agency* [Online]. Available: http://www.pia.gov.ph/news/index.php?article=451327469747#!prettyPhoto. [Accessed: January 2012]

[3] A. Jabines, and J. Inventor, *The Philippines: A Climate Hotspot Climate Change Impacts and the Philippines*, Greenpeace Southest Asia, Quezon City, Philippines, 2007.

[4] R.U. Solidum, "Vulnerability and resiliency of megacities to climate change and natural disasters," Paper presented at *International Conference on Green Urbanism 2011: Planning Greener Cities*, Quezon City, Philippines, 2011.

[5] V.P. Singh, and D.K. Frevert, *Watershed Models*, Taylor & Francis, Boca Raton, Florida, United States, 2006.

[6] M.P. Lim Suan, "Assessment of watershed technologies," *Journal of Philippine Development*, Vol. 26, No. 1, pp. 60-71, 1999.

[7] M.T. Fong, C.W. Downer, and A.R. Byrd, *A GSSHA Model of the Perris Basin of the San Jacinto River Watershed, Riverside County, California*, Coastal and Hydraulics Engineering Technical Note ERDC/CHL CHETN III-76, Army Engineer Research and Development Center, 2007.

[8] C.W. Downer, F.L. Ogden, J. Neidzialek, and S. Liu, "Gridded surface/subsurface hydrologic analysis (GSSHA) model: A model for simulating diverse streamflow-producing processes," In *Watershed Models*, Taylor & Francis, Boca Raton, Florida, United States, pp. 131-158, 2006.

[9] B.E. Johnson, C.W. Downer, and A.R. Byrd, "Application of a physically based distributed watershed model on the upper Auglaize watershed," In: *2009 Joint Conference - Lake Michigan: State of the Lake and Great Lakes Beach Association*, Milwaukee, Wisconsin, United States, pp. 1-22, 2009.

[10] M. Talebizadeh, S. Morid, M. Ghasemzadeh, and S.A. Ayyoubzadeh, "Uncertainty analysis in sediment load modeling using ANN and SWAT model," *Water Resources Management*, Vol. 24, No. 9, pp. 1747-1761, 2009.

[11] S.L. Neitsch, J.G. Arnold, J.R. Kiniry, and J.R. Williams, *Soil and Water Assessment Tool Theoretical Documentation Version 2005*, Agricultural Research Service and Texas Agricultural Experiment Station, Temple, Texas, 2005.

[12] F. Hao, X. Zhang, H. Cheng, C. Liu, and Z. Yang, "Runoff and sediment yield simulation in a large basin using GIS and a distributed hydrological model," In *GIS and Remote Sensing in Hydrology, Water Resources and Environment*, Y. Chen, K. Takara, I. Cluckie, and F. Hilaire De Smedt, eds.: International Association of

Hydrological Sciences (IAHS) Press, Oxford, United Kingdom, pp. 157-166, 2004.

[13] United States Department of Agriculture Soil Conservation Service (USDA-SCS), *National Engineering Handbook. Section 4, Hydrology*, USDA-SCS, Washington D.C., United States, 1972.

[14] J.R. Williams, "Chapter 25: The EPIC model," In *Computer Models of Watershed Hydrology*, V.P. Singh, ed.: Water Resources Publications, Colorado, United States, pp. 909-1000, 1995.

[15] Conference Scientific Committee, "Foreword to the 2009 international SWAT conference," In: *2009 International SWAT Conference*, Boulder, p. iii, 2009.

[16] H. Somura, I. Takeda, Y. Mori, D. Hoffman, and J. Arnold, "Application of the SWAT model to the Hii river basin, Shimani Prefecture, Japan," 2003 [PowerPoint slides]. Retrieved from https://swat.tamu.edu/docs/swat/conferences/2007/docs/session4/hiroaki%20somura.pdf

[17] J. Benaman, C.A. Shoemaker, and D.A. Haith, "Calibration and validation of soil and water assessment tool on an agricultural watershed in upstate New York," *Journal of Hydrologic Engineering*, Vol. 10, No. 5, pp. 363-374, 2005.

[18] J. Schoul, and K.C. Abbaspour, "Calibration and uncertainty issues of a hydrological model (SWAT) applied to West Africa," *Advances in Geosciences*, Vol. 9, pp. 137-143, 2006.

[19] A. Mishra, S. Kar, and V.P. Singh, "Prioritizing structural management by quantifying the effect of land use and land cover on watershed runoff and sediment yield," *Water Resources Management*, Vol. 21, No. 11, pp. 1899-1913, 2007.

[20] I. Wong, W.G. Booty, G. Benoy, C. Nielsen, P. Fong, and C. Mccrimmon, "Integrated land and water scenarios of the raisin river watershed using the SWAT model," *Water Quality Research Journal of Canada*, Vol. 44, No. 4, pp. 379-391, 2009.

[21] Z. Duan, X. Song, and J. Liu, "Application of SWAT for sediment yield estimation in a mountainous agricultural basin," In: *Proceedings of IEEE XPlore Conference: The 17th International Conference on Geoinformatics*, Fairfax, pp. 1-5, 2009.

[22] Office of the President, "PGMA comes to the rescue of Cagayan river basin; creates management office with P500-M fund," *Presidential Communications Operations Office, Philippine Information Agency*, 2008 [Online]. Available: http://www.op.gov.ph. [Accessed: May 2012]

[23] National Statistics Office, Data from: *Quickstat on Region II (Cagayan Valley)-August 2012* [dataset], Philippines Statistics Authority [Online]. Available: http://www.census.gov.ph/sites/default/files/ attachments/ird/quickstat/reg02_0.pdf. [Accessed: December 2012]

[24] Bureau Research Standard, Republic of the Philippines Department of Public Works and Highways (BRS-DPWH), "Water Resources Region No. 2 CAGAYAN VALLEY," In *Quezon City Streamflow Data Book 2*, Quezon City, Philippines, 2002.

[25] Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Data from: *Basin Information - Cagayan River Basin*, Department of Science and Technology. Available: http://kidlat. pagasa.dost.gov.ph/ffb/pabc.htm. [Accessed: May 2010]

[26] Japanese International Cooperation Agency (JICA), and Republic of the Philippines Department of Public Works and Highways (DPWH), *The Feasibility Study of the Flood Control Project for the Lower Cagayan River in the Republic of the Philippines*, Final Report Vol. 1 (2002) [Online]. Available: http://www.dpwh.gov.ph/infrastructure/JICA2/

[27] J. Richnavsky, B.Sir, P. Bobal, and J. Unucka, "Simulation of sediment transport in catchment using ArcSWAT 2005 dynamic erosion model exemplified by the catchment of the Ostravice river," *GeoScience Engineering*, Vol. 56, No. 1, pp. 27-35, 2010.
[28] M. Winchell, R. Srinivasan, J.M. Di Luzio, and J. Arnold, *ArcSWAT 2.3.4 Interface for SWAT2005: User's Guide*, Blackland Research Center: Texas Agricultural Experiment Station, Temple, Texas, United States, 2009.
[29] U.S. Geological Survey, *LEVEL-1 PRODUCT README: Geographic Tagged Image-File Format (GeoTIFF)*, 2009.
[30] J.A. Principe, *Exploring Climate Change Effects on Watershed Sediment Yield and Land Cover-Based Mitigation Measures Using SWAT Model, RS and GIS: Case of Cagayan River Basin*, Thesis (Master's), University of the Philippines Diliman, Quezon City, Philippines, 2012.
[31] Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), DMDG-F (Millennium Development Goals Fund) 1656 Fact Sheet #1 and #2, February 2010.
[32] R.G. Jones, M. Noguer, D.C. Hassell, D. Hudson, S.S. Wilson, G.J. Jenkins, and J.F.B. Mitchell, *Generating High Resolution Climate Change Scenarios using PRECIS*, Met Office Hadley Centre, Exeter, United Kingdom, 2004.
[33] Department of Environment and Natural Resources (DENR), *Regulations Governing the Establishment of Buffer Zones within Forest Lands (DENR Administrative Order 1992-No. 13)*, 1992.
[34] D.N. Moriasi, J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith, "Model evaluation guidelines for systematic quantification of accuracy in watershed simulations," *Transactions of the ASABE*, Vol. 50, pp. 885-900, 2007.
[35] A.W. Alansi, M.S.M. Amin, G.A. Halim, H.Z.M. Shafri, and W. Aimrun, "Validation of SWAT model for stream flow simulation and forecasting in Upper Bernam humid tropical river basin, Malaysia," *Hydrology and Earth System Sciences*, Vol. 6, pp. 7581-7609, 2009.
[36] H.V. Gupta, S. Sorooshian, and P.O. Yapo, "Status of automatic calibration for hydrologic models: comparison with multilevel expert calibration," *Journal of Hydrologic Engineering*, Vol. 4, No. 2, pp. 135-143, 1999.
[37] N. Hudson, *Soil Conservation*, Iowa State University Press, Ames, Iowa, 1995.
[38] N.R. Alibuyog, V.B. Ella, M.R. Reyes, R. Srinivasan, C. Heatwole, and T.A. Dillaha, "Predicting the effects of land use on runoff and sediment yields in selected sub-watersheds of the manupali river using the ArcSWAT model," In: *Soil and Water Assessment Tool (SWAT): Global Applications*, World Association of Soil and Water Conservation, pp. 253-266, 2009.
[39] Food and Agriculture Organization (1998). *Soil Resource Depreciation and Deforestation: Philippine Case Study in Resource Accounting,* Rome, Italy.
[40] V.B. Asio, R. Jahn, F.O. Perez, I.A. Navarrete, and S. Jr. M. Abit, "A review of soil degradation in the Philippines," *Annals of Tropical Research*, Vol. 31, No. 2, pp. 69-94, 2009.
[41] Intergovernmental Panel on Climate Change (IPCC), *Climate Change 2007: Synthesis Report*, Valencia, 2007.