INTEGRATED USE OF REMOTE SENSING, GIS AND SWAT MODEL TO EXPLORE CLIMATE CHANGE EFFECTS ON RIVER DISCHARGE IN THE CAGAYAN RIVER BASIN AND LAND COVER-BASED ADAPTATION MEASURES

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ABSTRACT: Land cover-based adaptation measures have already been adopted by many concerned institutions in response to the posing ill-effects of climate change. Such scheme is usually achieved using an integration of watershed models, Remote Sensing (RS) and Geographic Information System (GIS). In this study, GIS provided the platform for the ArcSWAT interface of the Soil and Water Assessment Tool (SWAT) model. The model was used to assess the effect of climate change on river discharges from the Cagayan River Basin—the largest river basin in the Philippines—with inputs including land use/land cover maps from RS data (Landsat TM and ETM+ images), Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM), soil map and hydrologic data. Automatic watershed delineation was done via the ArcSWAT interface using the input DEM while subbasins and finer subdivisions in the basin called the hydrologic response units (HRU) are defined by setting threshold limits for land use/land cover, soil type and slope class. Values of the Nash-Sutcliffe Efficiency (NSE)>0.6 and coefficient of determination (R^2)>0.7 for both model calibration and validation of mean daily river discharges showed that SWAT can realistically model flow dynamics in the study area. Reruns of the calibrated model have demonstrated how changes in climatic parameters, such as rainfall and temperature, can significantly affect river discharge. Specifically, it has been shown that discharge will increase for A1B climate change scenario in years 2020 and 2050 and in general, the proposed land cover distribution scheme has become a control mechanism by successfully reducing river discharge. The study has demonstrated how the integration of RS, GIS and SWAT model can be a powerful tool in watershed management and protection.

1. INTRODUCTION

Monitoring river discharges is important to watershed management because it affects the surrounding community's water budget requirement, flood prediction efforts, and water quality and sediment discharge dynamics of the basin. This has been proven a fact in view of the recent disasters that have befallen the Philippines including the flash flood in Cagayan De Oro, Northern Mindanao that claimed many lives and destroyed infrastructures and sources of community's livelihood and the upwelling of the Cagayan River that inundated rice fields and other crops that were supposed to be harvested in few weeks' time. The Philippine government has this in mind in putting up the River Basin Control Office whose second agenda targets flood mitigation among others in the major river basins of the country (RBCO, 2007).

Observed and projected changes in the climate regime are expected to aggravate watershed management problems. The evaluation of climate change and its variability is of great benefit to economically developing nations since population in these regions depends extensively on climate for their welfare (Pal, et al., 2007). Tagged as a climate hotspot (Jabines & Inventor, 2007), the Philippines is likely to be adversely affected by any change in its climate since its economy is highly dependent on agriculture and natural resources (CAD-PAGASA, 2004). It is therefore important that river flows are efficiently monitored and well-studied incorporating adaptation measures to address the ill-effects of climate change.

Adaptation measures are "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (UNFCCC, 2012). Riparian reforestation and afforestation of hilly and mountainous areas were the two land cover-based adaptation measures that were proposed and utilized in this study, the effect of which were analyzed in terms of how they can successfully help in controlling river discharges vis-à-vis climate change.

2. THE STUDY AREA

2.1. Location and Topography

The Cagayan River Basin (CRB)—the largest river basin in the Philippines (Office of the President, 2008)—is located in the Northeastern portion of Luzon island bounded by 15^{0}52'N-18^{0}23'N latitudes and 120^{0}51'E-122^{0}19'E longitudes (Figure 1). Its drainage area is approximately 27,700 km^2 and covers the provinces of Cagayan, Isabela, Nueva Vizcaya, Quirino, Mountain Province, Ifugao, Kalinga, Apayao and Aurora (RBCO, 2007). CRB's major tributaries are the Chico, Siffu-Mallig and Magat in the left bank and Pared, Tuguegarao, Tumauni and Ilagan in the right bank (DPWH & JICA, 2001). Approximately 50% of the area is relatively flat with slope that varies from 0-17% while 33% of the area has slope between 17-42% and the rest are with slope greater than 42% based on a slope map derived from the SRTM-DEM. The basin is also surrounded by three mountain ranges: Sierra Madre, Cordillera Central and Caraballo-Maparang in the East, West and South respectively (DPWH & JICA, 2001).

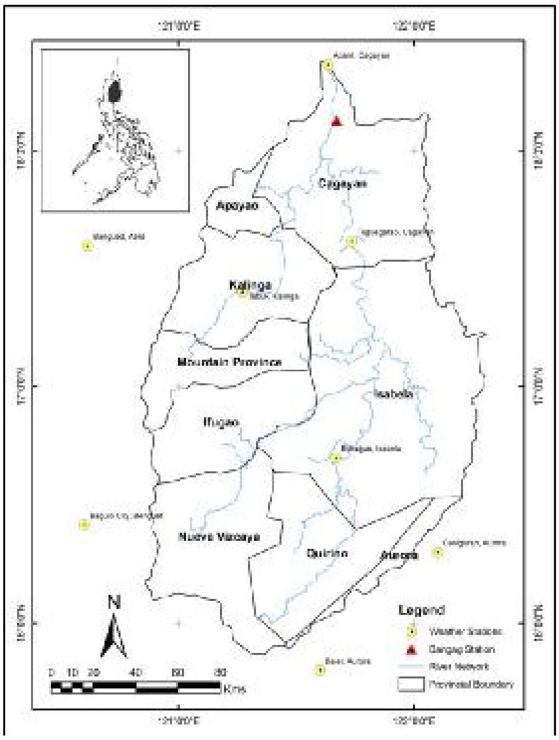

Figure 1. The Cagayan River Basin, its provinces, the Bangag gauging station and weather stations.

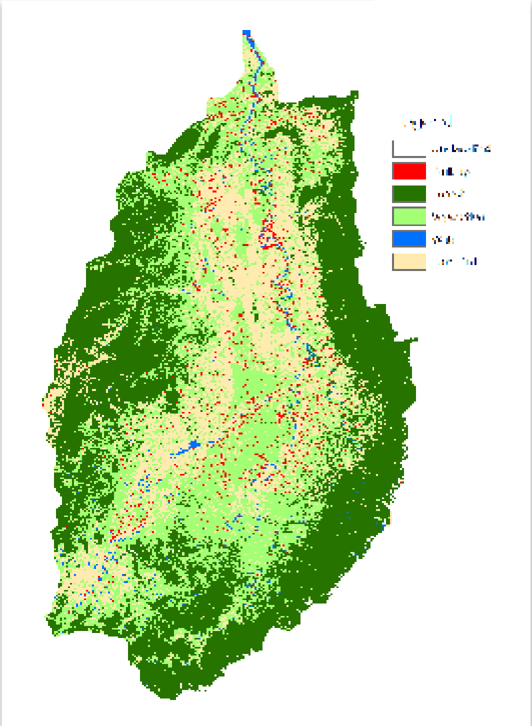

Figure 2. Land use/cover map of CRB using Maximum Likelihood Classifier

2.2. Climate and Land Use/Cover

The Cagayan Valley region where CRB is located falls under Type III climate zone which is characterized by no pronounced maximum rain period and a short dry period (BRS-DPWH, 2002). According to PAGASA (2009), the northern part of the basin has an average annual rainfall of 1,000 mm and 3,000 mm in the southern mountains. The mean annual temperature and average relative humidity are 23.6-26.0^{0}C and 75-85%, respectively. According to DPWH & JICA (2001), about 37% of the area is covered by forest while grassland, agricultural area, and other land use such as settlement and water area occupies 34%, 27% and 2%, respectively. Of the 7,410 km^2 of agricultural area, 94% of it is crop fields while the rest are fruit trees. The crop fields are further subdivided into 68% paddy field, 22% corn field and 10% upland crop field.

2.3. Hydrology and Inundation

According to a report of a study done by DPWH and JICA (2001), the basin has an estimated mean annual runoff of 1,343 m^3/s at the mouth of the Cagayan River with a 100 year probable flood estimated to be 21,400 m^3/s at the mouth under the present river condition. The same study has also estimated flood prone areas of 1,860 km^2 brought by the biggest flooding that occurred on 1973 while the next big flood that occurred on 1980 inundated an area of 1,740 km^2. These flooding events have severely affected the livelihood of the community in the area because the said areas are presently devoted to production of rice, corn, legumes and vegetables.

3. 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” (Neitsch et. al, 2005). The model is physically based, uses readily available inputs, computationally efficient and enables users to study long-term impacts. SWAT is a continuous time model and is not designated to simulate detailed single-event flood routing (Neitsch et. al, 2005) and operates on a daily time step (Hao et. al, 2003).

To predict surface runoff yield, the model uses a modified version of the SCS CN method (USDA-SCS, 1972):

$$Q = (R - 2S)^2 / (R + 0.8S) \qquad R > 0.2S \tag{1}$$

$$Q = 0 \qquad R \le 0.2S \tag{2}$$

where Q and R are the daily surface runoff and daily rainfall, respectively, both in mm H_2O. S is a retention parameter which varies spatially under various soil, land use, management and slope conditions, and temporally to respond to changes in soil water content (Hao et. al, 2003). The retention parameter is related to the curve number (CN) and defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{3}$$

4. METHODOLOGY

The general procedure used in the study can be seen in Figure 3. Several data sets are prepared to be inputted to the SWAT Model. Model setup includes watershed delineation via the SWAT model interface in ArcGIS™ (ArcSWAT) using the input DEM (90-m SRTM-DEM) while subbasins and finer subdivisions in the basin called the hydrologic response units (HRU) are defined by setting threshold limits for land use/land cover, soil type and slope class. River discharge data were divided into two sets, one used for model calibration while the other for validation. A sensitivity analysis is also done to identify and rank parameters that have significant impact on streamflow (Saltelli et. al, 2000). The model is then rerun under three scenarios: base, with climate change, and with adaptation measures.

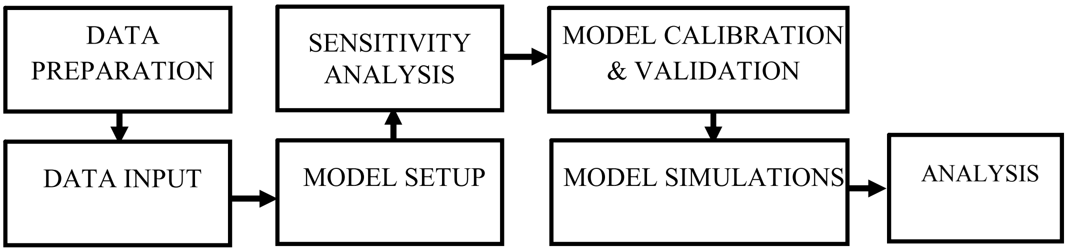

Figure 3. General procedure used in the Study.

4.1. Data Preparation

4.1.1. Land Use/Cover Map of the Cagayan River basin was generated using Landsat 5 TM and 7 ETM+ images covered by path 116 and rows 47, 48 and 49. These satellite images are atmospherically corrected using Dark Object Subtraction (DOS) technique in ENVI®. About 1% to 10% of the Landsat scenes are covered by cloud and shadows which are filled in using a modified version of a method proposed by Martinuzzi *et. al* (2006). Four supervised classifiers (Maximum likelihood, Parallelepiped, Minimum Distance and Mahalanobis Distance) and two unsupervised classifiers (ISODATA and K-means) were then applied to the processed images. The final classifier, Maximum Likelihood, was selected because it produced the highest overall accuracy and kappa coefficient (κ) values (Table 1). The land cover map as shown in Figure 2 is a mosaic of the three separately classified image generated using Maximum Likelihood classifier and post-processed using Majority Analysis to eliminate “salt and pepper” effects. Land cover classes are converted to their equivalent SWAT LULC classes (Table 1) to be compatible with the model’s LULC data input requirement. Unclassified pixels are assigned to AGRL because by visual inspection, these pixels occupy agricultural areas in the Cagayan River Basin.

Table 1. Over-all accuracy and kappa coefficient of image classifiers tested.

CLASSIFIER	OVER-ALL ACCURACY	KAPPA COEFFICIENT
Maximum Likelihood	91.07	0.88
Parallelepiped	47.66	0.34
Minimum Distance	85.77	0.87
Mahalanobis Distance	88.62	0.87
ISODATA	64.75	0.73
K-Means	64.75	0.73

Table 2. User-defined Land use/land cover (LULC) classes and their corresponding SWAT LULC classes

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

4.1.2. Soil Data was generated from the Bureau of Soils and Water Management (BSWM) data which includes Pit Profile Descriptions (PPD), Laboratory Analysis (LA) and Auger Boring Descriptions (ABD) of Cagayan, Isabela and Nueva Vizcaya provinces.

4.1.3. Weather Stations consist of three main and five rainfall stations (Figure 1) from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and Weather Underground (http://www.wunderground.com). The three main weather stations consist of rainfall, temperature and humidity data and are located in the provinces of Cagayan and Isabela while the rainfall stations are distributed in the Aurora, Kalinga and nearby provinces not covered by CRB.

4.1.4. Climate Change Data were extracted from the report published by PAGASA (2010). These include projected changes in mean seasonal temperature (^{0}C) and rainfall (%) which are outputs of the agency's run of the Providing Regional Climates for Impact Studies (PRECIS) model using A1B scenario in time slices centered at years 2020 and 2050. These projected incremental changes in rainfall and temperature are inputted to the model by editing the RFINC(mon) and TMPINC(mon), respectively, in the .SUB files of the SWAT model run files. Figure 4 shows a sample plot of these data for season SON (Sep-Oct-Nov).

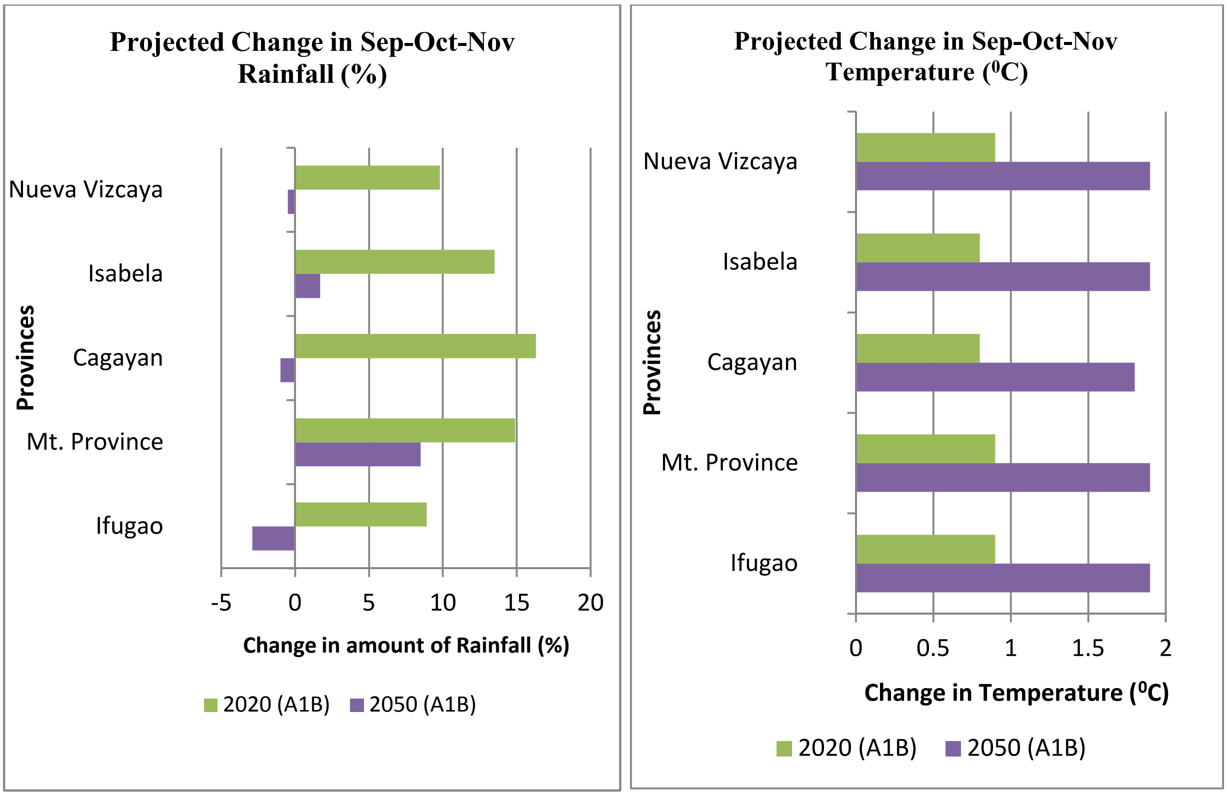

Figure 4. Projected change in mean seasonal rainfall (%) and temprature (^{0}C) under the A1B climate change scenario in the provinces covered by the Cagayan River Basin.

4.1.5. River Discharge Data were daily values from the Bureau of Research and Standards (BRS). Figure 5 shows this data plotted with rainfall for the Bangag station (Figure 1) where model calibration and validation were done.

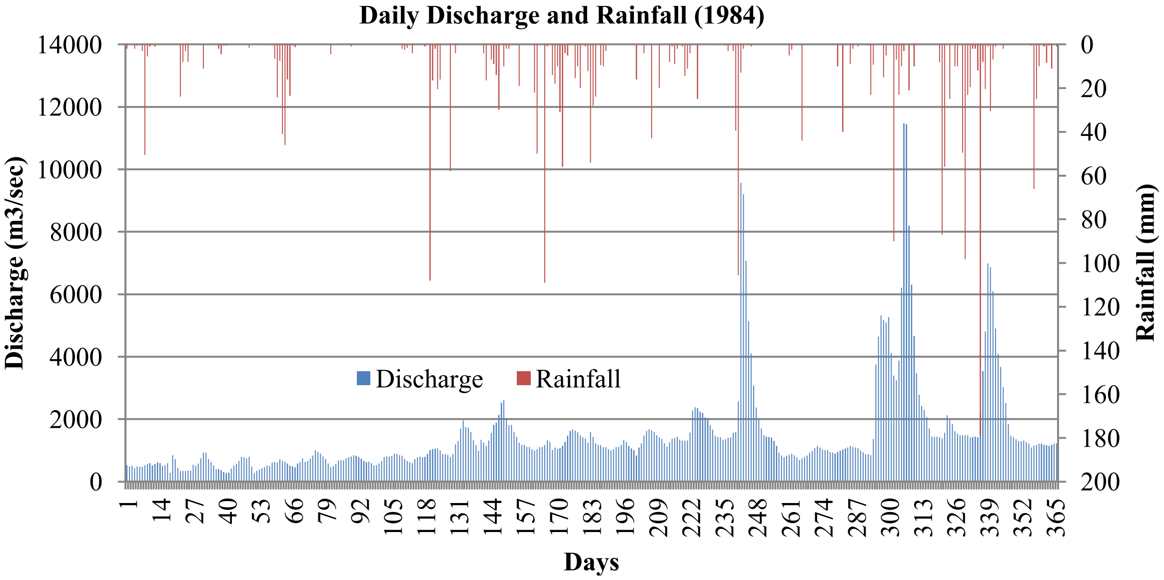

Figure 5. Daily 1984 discharge and rainfall at Bangag station in Lallo, Cagayan for flow calibration.

4.2. Evaluation of Model Performance

The model was evaluated using four quantitative statistics as recommended and used by Moriasi *et. al* (2007) and Duan *et. al* (2009). 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):

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_{obs}^{mean} \right)^2} \right] \tag{4}$$

$$PBIAS = \frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right) * (100)}{\sum_{i=1}^{n} Y_i^{obs}} \tag{5}$$

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}}{\sqrt{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_{obs}^{mean} \right)^2}} \tag{6}$$

$$R^2 = \frac{\left(\sum_{i=1}^{n} \left(Y_i^{obs} - Y_{obs}^{mean} \right) \left(Y_i^{sim} - Y_{sim}^{mean} \right) \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_{obs}^{mean} \right)^2 \sum_{i=1}^{n} \left(Y_i^{sim} - Y_{sim}^{mean} \right)^2} \tag{7}$$

Where Y_i^{obs} and Y_i^{sim} are values for the i^{th} observation and simulated data for flow, respectively, and *n* is the total number of observations. Y_{obs}^{mean} and Y_{sim}^{mean} correspond to the mean of the observed and simulated values. NSE indicates how well the plot of observed versus simulated values fits the 1:1 line (Alansi *et. al*, 2009); PBIAS measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta *et. al*, 1999); RSR is the ratio of the Root Mean Square Error and the standard deviation of measured data (RMSE) (Moriasi *et. al*, 2007); and R^2 is an indicator of relationship strength between the observed and simulated values

(Alansi *et. al*, 2009). In general, model simulation can be judged as satisfactory if NSE>0.40 and R^2>0.5 (Duan *et. al*, 2009), and if RSR≤0.70 and PBIAS ±25% for streamflow (Moriasi *et. al*, 2007)

4.3. River Discharge Simulations

The calibrated model is run under three scenarios: (1) base scenario using original set of weather and land cover data; (2) incorporating climate change data; and (3) incorporating adaptation measures. The river discharge (flow) was evaluated at reach number 30 located in subbasin 30 in the Province of Nueva Vizcaya (Figure 1 and Figure 6) since this is the subbasin where intensive adaptation measures are to be applied.

4.4. The Proposed Land Cover-Based Adaptation Measures

The two land cover-based adaptation measures proposed in this study are riparian reforestation and afforestation of hilly and mountainous areas (Figure 6). To model riparian reforestation, a buffer zone of 20 m was demarcated from the river's reach (LULC is WATR). This buffer distance is the width of a 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 the Philippine Department of Environment and Natural Resources Administrative Order (DAO) No. 13 (DENR, 1992). Meanwhile, 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 areas for afforestation do not contain any built-up areas (URML) and thus, no restriction on land use conversion is expected.

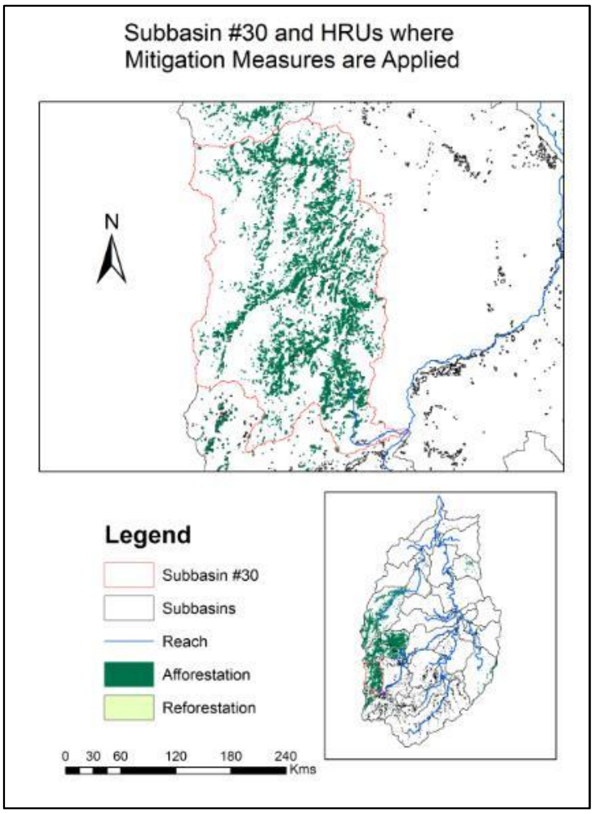

Figure 6. The subbasin 30 and HRUs where adaptation measures are applied.

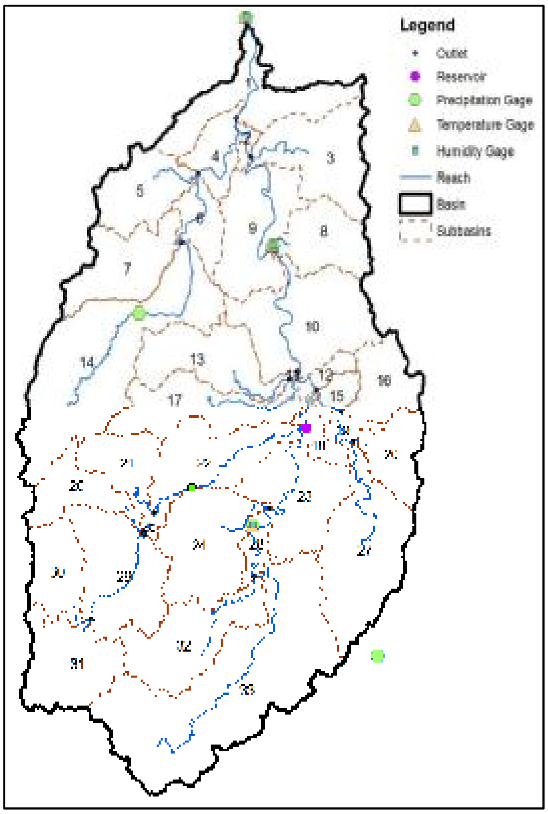

Figure 7. Delineated Cagayan River Basin and its 33 subbasins delineated using ArcSWAT.

5. RESULTS AND DISCUSSION

5.1. Watershed Delineation

The Cagayan River Basin was automatically delineated by ArcSWAT using model inputs such as the SRTM-DEM and its user-defined mask while weather stations are mapped using their location tables. The output map in Figure 7 which shows the boundary of CRB, its reach (river and its tributaries), the 33 suggested monitoring stations or outlets, the 33 subbasins or subwatersheds, the user-defined reservoir, as well as the location of rainfall, temperature and humidity gages is generated after automatic watershed delineation and model setup. There are a total of 522 HRUs that were defined in the basin.

5.2. Model Calibration and Validation

SWAT model was calibrated and validated for flow at the Bangag station in Lallo, Cayagan (Figure 1). Table 3 shows the five most sensitive flow parameters and their corresponding default and final values after model calibration. For a more detailed description of these parameters, the reader may refer to the Theoretical Documentation of SWAT 2005 (Neitsch *et. al*, 2005).

For model validation, the calibrated model is rerun for another period (1985-1986) which is different from the calibration period (1984) stage. The results of model calibration and validation for flow are summarized in Table 4. Meanwhile, the simulated discharges are plotted with the observed data in Figure 8 for visual comparison. It can be noted that using these plots, it can be inferred that a better SWAT model simulation in high flows is achieved compared in low flows. This same observation was also reported by Geza and McCray (2008).

It can be shown in Table 3 that the model has performed satisfactorily during calibration and validation stages since values of the four statistical indicators of model efficiency are above the minimum values set for a satisfactory run (i.e., NES>0.40, R^2>0.5, RSR≤0.70, and PBIAS ±25%), except for the average monthly flow where RSR>0.70. This result suggests that in terms of stream flow in the Cagayan River Basin, it is advisable to use daily values in flow modeling since monthly average values cannot capture the discharge fluctuations effectively. 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 3. Default and Final Values of SWAT calibration parameters for flow.

Variable	Parameter	File	iMet*	Range	Default Value	Final Value (for iMet)
Flow	Alpha_Bf	.gw	1	[0, 1]	0.048	0.26
	Ch_K2	.rte	1	0-150	0	25
	Cn2	.mgt	3	[-25, 25]	varied by LU	1.23745
	Esco	.hru	1	[0, 1]	0	1
	Gwqmn	.gw	2	[0,1000]	0	-263.22

* variation method: 1 = replacement of initial parameter by value, 2 = adding value to the initial parameter, 3 = multiplying initial parameter by a value in percentage

Table 4. SWAT Performance during model calibration and validation.

Calibration					
Period	Time Step	NSE	R^2	RSR	PBIAS
1984	Daily	0.89	0.74	0.34	17.64
	Monthly	0.47	0.83	0.73	17.75
Validation					
Period	Time Step	NSE	R^2	RSR	PBIAS
1985-1986	Daily	0.62	0.58	0.61	23.22
	Monthly	0.43	0.64	0.75	32.45

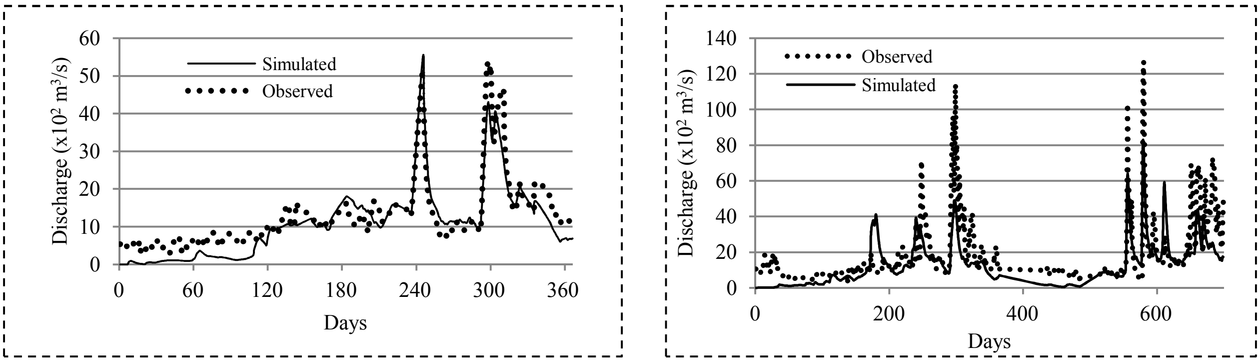

Figure 8. Observed and simulated discharge (flow) at Bangag station during model calibration (left) and validation (right).

5.3. Simulated River Discharges

The analysis of simulated river discharges was done in two approaches: first in per season basis and then in annual basis. The first approach was done due to the fact that stream flows change during different seasons of the year. Moreover, the climate change data from PAGASA were in per season basis (i.e., one projected change in mean temperature and rainfall per season). The four seasons defined are December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON). However, the last approach is also done because it is also quite interesting to look at the annual river discharge when doing comparison among the base, climate change and adaptation scenarios.

5.3.1. Base and Climate Change Scenarios. Figure 9 shows a graph of the simulated discharges for the base scenario and the two climate change scenarios (A1B 2020 and A1B 2050). Consistent for these three scenarios is the peak flow occurring in the JJA season followed by SON, MAM and DJF. The graph also revealed that while there are negligible decreases (mean change of 3 m^3/s) in simulated flow for the other seasons, the increase in discharge for the JJA season is significant (mean change of 66 m^3/s) when compared to the base scenario.

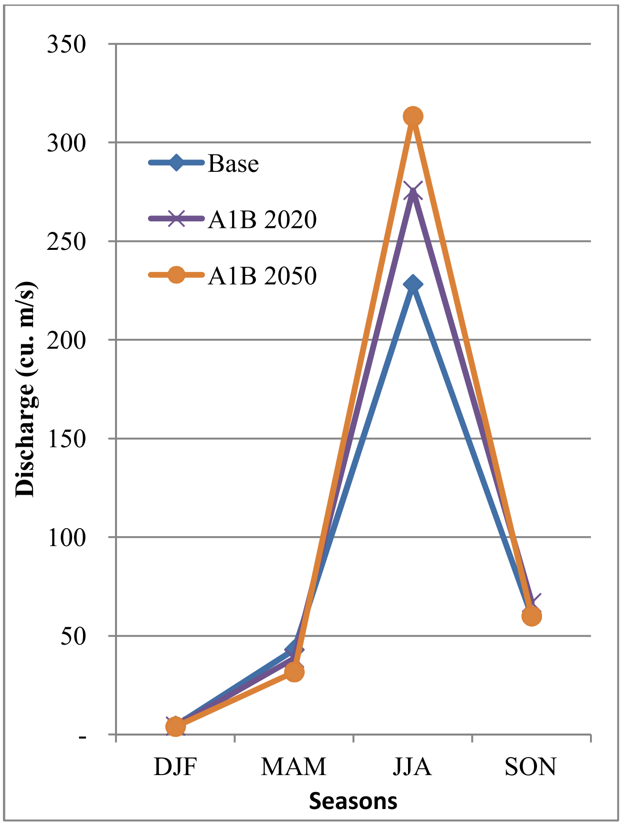

Figure 9. Simulated river discharges under the base and climate change scenarios.

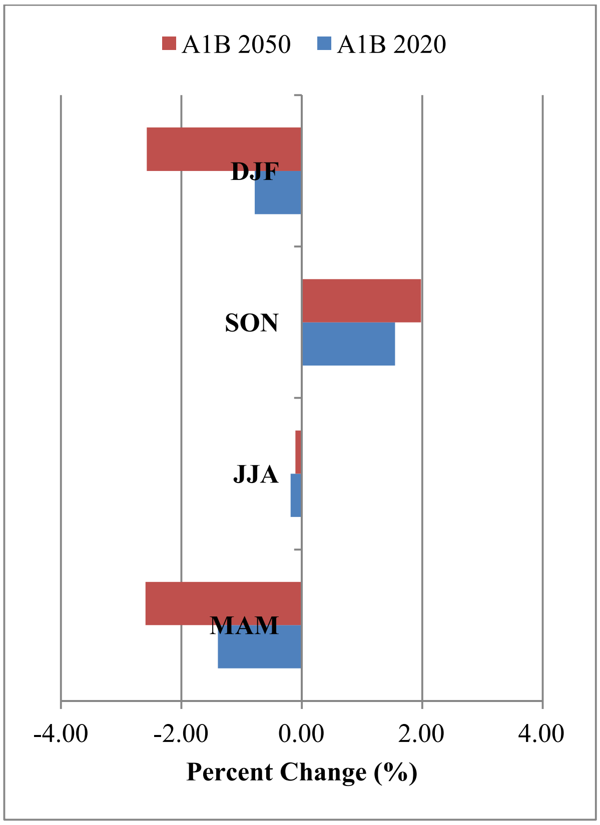

Figure 10. Change in river discharge after application of adaptation measures

5.3.2. Climate Change Scenarios and Adaptation Measures. The goal of riparian reforestation and afforestation of hilly and mountainous areas is to lower down future river discharges amidst the impending effects of climate change. As stated earlier, the effects of the proposed adaptation measures are evaluated at reach 30 located at subbasin 30 (Figure 6) because much of the reforestation and afforestation efforts were proposed to be done here. Figure 10 shows the effects of these mitigating measures to river discharges. The result shows that in general, the proposed mitigating measures have successfully decreased river flows except during the SON season that can be attributed to the projected change in precipitation for A1B which is higher than the baseline scenario (CAD-PAGASA, 2004).

5.3.3. Simulated Mean Annual Discharges. Figure 11 shows the simulated mean annual discharge for different scenarios: base, climate change scenarios (A1B 2020, A1B 2050) and climate change with adaptation measures (A1B 2020 AM, A1B 2050 AM). The graph clearly shows how projected changes in the climate can increase the river discharge in the future compared to the present (base) scenario. The adaptation measures applied has successfully reduced river discharge for both climate change scenarios.

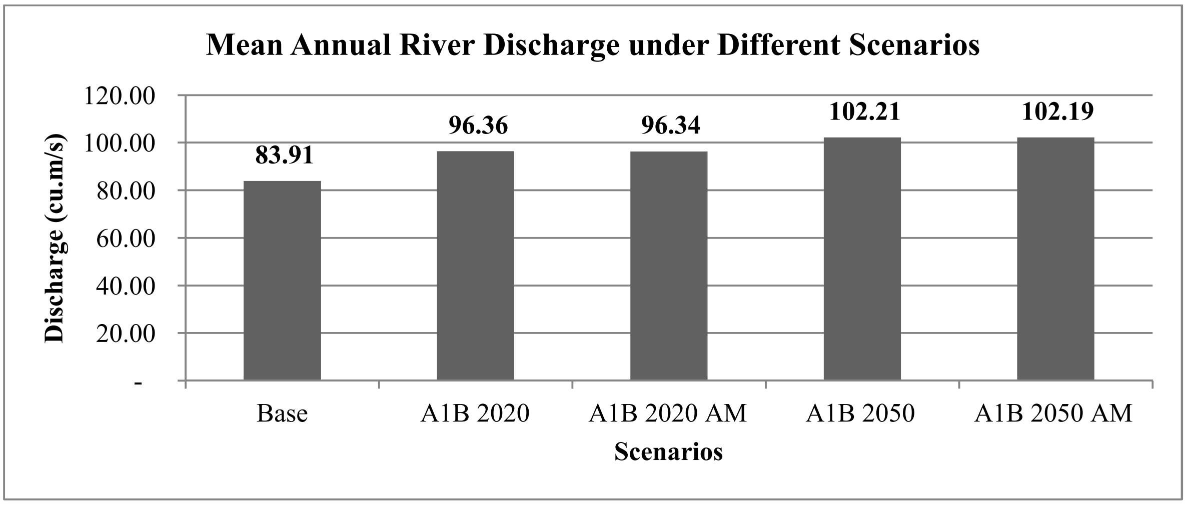

Figure 11. Mean annual river discharge under different scenarios.

6. CONCLUSION

The study has simulated the river discharge in one of the reaches of the Cagayan River Basin. In general, climate change will bring increased flows especially during the June-July-August season while application of the proposed land cover-based adaptation measures has reduced the flow. Concerned authorities should look deeper into the flooding problems in the CRB because according to the results of this study, even with reforestation efforts, the river discharge is still expected to go higher than its present scenario.

Although quite negligible (about -0.02%), the reduction of river discharge after applying adaptation measures may have considerable effects to other variables affecting the basin such as sediment yield. Sediment discharge modeling is the next phase of the study which is very significant because of its effects on soil loss—a major concern in the mountainous areas of the Cagayan River Basin.

The study has demonstrated how the integration of Remote Sensing, Geographic Information System and watershed models can be a powerful tool in watershed management and protection specifically, in combating the possible ill-effects of climate change.

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