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APPLYING SWAT TO PREDICT IMPACT OF LANDUSE CHANGE ON HIDROLOGICAL RESPONE IN UPPER CIMANUK CATCHMENT AREA

Iwan Ridwansyah[1)], Asep Sapei[2)], Machmud A. Raimadoya[2)]

[1] Research Centre for Limnology, Indonesian Institute of Science.
[2] Civil engineering and environment, Bogor Agricultural University
iwanridwansyah@gmail.com

ABSTRACT

Cimanuk River which catchment area of 3,752 km^2 is the longest river in West Java. Increasing population growth with rapid changes of other aspects such as social and economy. Based on Watershed Management (BPDAS) for Cimanuk-Citanduy data, during 1995-2003 about 400,000 trees in forest of Cimanuk catchment area were loss due to illegal logging and agriculture area demand. Landuse in upper cimanuk catchment area has changed, the most changes is conversion to settlement areas. During 1991-2002, conversion of plantation to settlement area was about 131.2 Ha, that of paddy field to settlement was 323.9 Ha, while that of un-irrigated agriculture to settlement was 91.9 Ha. The converted areas became larger in 2005, whereas plantation was 169 Ha, paddy field was 258.9 Ha and agricultural area was 274.4 Ha. Forest and paddy field areas were relatively smaller in Upper Cimanuk Catchment area. However, landuse change such as increment of the settlement or agricultural areas has a profound impact on runoff hydrographs. The general objective of the research was to develop SWAT and GIS model to investigate impact on landcover change to water yield and landuse optimization in Upper Cimanuk Catchment Area. The SWAT simulation is done during 2004 – 2005 and the validation was done for landuse 2005. The calibration of model resulted showed R^2 which is 0.636 and The Nash Sutcliffe efficiency (NSE) 0.49. This simulation resulted 15.32 mm for total surface runoff and 711.2 mm for total water yield. Those numbers can infer that catchment condition was much better than the simulated landuse of 2002 condition, where the value of surface runoff was 20.75 mm and total water yield was 718.8 mm. The result SWAT simulation for 1991 was better catchment condition, where value of surface runoff was 15.3 mm and water yield was 711.2 mm.

Keywords: *GIS, SWAT, water yield, landuse optimizing and catchment.*

INTRODUCTION

Cimanuk River which catchment area of 3,752 km^2 is the longest river in West Java which has an important meaning for people living around the river, the river flows from Garut district through Cimanuk delta of Indramayu and Cirebon district. Increasing population growth with rapid changes of other aspects such as social and economy, lead to increasing demand of settlement or agriculture area. However, impact of landuse change, such as the extension of settlement or agricultural area, has a profound impact on runoff hydrographs. Increased impervious surfaces are a common cause of increased peak-runoff volumes. This condition will increase erosion, sedimentation on water body, decrease water resources, increase agricultural pollutant, landslide and decrease agricultural production. Now erosion in Cimanuk Watershed reaches 25 ton or 4.3 million m^3 sediment per year (PU executive summary).

The availability of GIS tools and more powerful computing facilities make it possible to handle difficult and limitation of model simulation. The Tools can develop distributed continuous time basin-scale models, based on availability of regional information. Recently several developed models are provided for erosion simulation on basin scale, such as: SWRRB (Simulator for Water Resources in Rural Basins), SWAT (Soil and Water Assessment Tools) and SWIM (Soil Water Models). SWAT is a physically based continuous event hydrology model developed to predict the impact of land management practice on water, sediment, and agricultural chemical yield in large, complex watershed with varying soils, landuse, and management condition over long period of time.

The study on impact of landuse change on hydrological system can be done in three steps; Development of landuse change scenario, Simulation of Hydrology region, and Evaluation on variable hydrologic response of water resources. Landuse change pattern will decrease the region of water availability which can lead to extreme discharge fluctuation, i.e. extreme drought and extreme flood (Pawitan, 1999).

The objective of the research is to develop SWAT and GIS model to investigate impact of landuse change to water discharge in Upper Cimanuk Catchment Area (UCCA).

METHODS

The study covers the period of March to July 2009, but collection of data has been done since 2006. The study area is located in UCCA. Located at 107^o 42' 21" E – 107^o 58' 32" E and 7^o 7' 4" S – 7^o 24' 45" S, it has on area about 4486 km^2. Administratively the study area belongs to Garut Regency and approximately 6 hours away from Jakarta. Based on Statistical Bureau data the population of Garut regency consists of 2.196 million people in 2005.

The methodology of this study is limited to the condition of the data and used hydrology model application SWAT for MapWindows (MWSWAT). MWSWAT is a graphical user interface, written in FORTRAN language (www.waterbase.org) and ***MapWindow*** is an open source "Programmable Geographic Information System" that supports manipulation, analysis, and viewing of geospatial data and associated attribute data in several standard GIS data formats.

The integration GIS, remote sensing and SWAT model was divided into three major steps, as follows; (1) SWAT model, Calibration and Validation, (2) Landuse Change analysis and (3) Impact of Landuse change to hydrology response. The study started by data preparation all spatial data, then landuse data series are definite to SWAT model landuse database and developed soil database, landuse series data is also prepared for crosstab process to detect landuse change. Next step of study is Simulated MWSWAT model, then calibrating the output of SWAT simulation. After the validation is enough the study is continued by analysis of landuse change using cross table of landuse series data and then each landuse data is simulated by SWAT model.

Landuse is one of the dynamic parameters caused by human activities. Change detection is the process of identifying the state of an object or phenomenon by observing it at different times (Singh, 1989 in Ernani, 2006) Several landuse data series have been classified by Hydro-informatics Laboratory in Research Centre for Limnology, Indonesia Institute of Science. The classification has been compared with field data and the accuracy of classification is about 82.7% (Daruati, 2008). Landuse change analysis uses post classification comparison and time series analysis (cross tab).

Within the process of setting up the model run/input files with MWSWAT a series of operations are required. The first step in hydrologic data development for hydrology model SWAT is defining catchment area boundaries. These boundaries normally fall along the ridges in a watershed. On one side of the ridge, water flows into the watershed, while on the other side of the ridge, water flows into a separate watershed, after stream and sub-catchment delineated, the next step is creation of Hydrological Response Units (HRUs). An HRU is an intersection of sub-catchment polygon with landuse, soil type and slope. HRUs has a unique combination between landuse, soil characteristics and slope. In this research a second option is used for UCCA.

SWAT database used weather station and location and stored in wgnstation.dbf. The UCCA used one weather station and three locations for rain gauge. The weather station belongs to Plantation Company, while Rain Gauge belongs to Geophysics Agency (BMG) and The Public Work Ministry (PU). After data file has been generated, SWAT model in Upper Cimanuk Catchment area is ready to simulate. The simulation is done on 2005 landuse data.

RESULT AND DISCUSSION

Landuse Change Analyses

Multi-data Landsat Image (1991, 2002 and 2005) were classified. The areas of each landcover class were calculated. The percentage of landuse change during 1991 – 2005 is shown in Table 1. During 1991 – 2005 some areas were decreasing, such as forest, plantation, paddy and brush. The increasing percentage was for settlement and agriculture areas.

During 1991 – 2002, most landcover changed to bare land area, and then the second is settlement area. The area for settlement increased 27.2% or 541 ha and the changes continued during 2002 – 2005 which became 19.3% or 605 ha. The total changes settlement area during 1991-2005 is increase about 57.5% or 1147.1 ha. Whereas the condition of forest was different, during 1991- 2002 forest area decreased to 18.6% or 1,832.8 ha, and the next period (2002-2005) the forest area increased about 3.2% or 2661 ha. The deforestation is appropriate to BKSDA report in Zuhri and Sulistiawaty (2007), where deforestation in Papandayan Mountain reserve reached about 340.8 ha during 1996-2003 caused by illegal logging. The increase of forest area during 2002-2005 is caused by re-forestation by the Ministry of Forest. With the result that total changes of forest area during 1991 – 2005 decreased about 15.9% or 1,566.7 ha.

Table 1. Percentage of variation of landuse change in Upper Cimanuk Catchment Area

Landuse	LU 1991	LU 2002	LUe 2005	% Change 91-02	% Change 02-05	% Change 91-05
Forest	9866.5	8033.7	8299.8	-18.6	3.2	-15.9
Plantation	10457.3	10632.1	10220.4	1.7	-4.0	-2.3
Agriculture	11990.2	13253.9	13197.5	10.5	-0.4	10.1
Settlement	1994.3	2536.2	3141.5	27.2	19.3	57.5
Paddy field	9304.0	9029.6	8799.1	-2.9	-2.6	-5.4
Brush	1250.5	1227.6	1223.0	-1.8	-0.4	-2.2
Bare land	32.4	171.2	0.0	429.1	-100.0	-100.0

The table also shows the increase of agriculture areas, in 1991 – 2002 agriculture area increased to 10.5% or 1263.7 ha but during 2002 – 2005 agriculture area decreased to 0.4% in total agriculture areas during 1991 – 2005 increased to 10.1% or 1207.3 ha. The higher changes of landuse is to became bare land, during 1991-2002 this landuse increased to 429.1% or 138.8 ha, but during 2002-2005 bare land areas changed to other landuse class.

Distribution of Landuse Change

The largest landuse change during 1991-2002 was conversion from forest to plantation for about 1,338.9 ha. Forest area was also reduced to 2,112 Ha due to its conversion into plantation, agriculture, and bare land. Cross table also shows that about 571 ha area was converted into settlement areas; this number was resulted from the change from plantation, agriculture, paddy field, brush and bare land areas. During the second period (2002 – 2005) about 141.6 ha forest was converted to plantation and 8.0 ha to agriculture. Additional to that, about 404.4 ha of plantation and 9.7 ha of agriculture area were reforested, many landuse classes have been converted into urban areas. Landuse change reached 711 ha and this value is higher compare to the first period which has longer duration.

Table 2. Result of cross tabulation (1991 – 2005)

1991/2005	Forest	Plantation	Agriculture	Settlement	Paddy	Brush	Bareland	Water body
Forest	8132.94	955.62	772.11					
Plantation	161.91	9253.35	731.25	314.7				
Agriculture			11670.84	318.7	2.43			
Settlement				1975.0				
Paddy		14.04		561.2	8743.8	0		
Brush				27.0	0	1224		
Bareland				4.1	14.04		0	
Waterbody								16.9
Total changes	161.91	969.66	1503.36	1225.7	16.47			

Total distribution of landuse change during 1991 to 2005 is presented in Table 2. The table shows that the largest landuse change is deforestation into plantation (955.6 ha). Aside from that, reforestation occurred in about 161.9 ha. In the east area most changes was conversion to agriculture area; about 772 ha forest area converted to agriculture which was mainly in mountain area. The table also shows that about 1225 ha is converted to settlement area; these numbers was resulted from plantation, Agriculture, Paddy, and brush. The increasing of settlement area or urbanization drives the change of landuse pattern, which may also have adverse impact on ecological of area, especially hydro-geomorphology and vegetation (Long *et al*, 2008).

SWAT Model

After input file have been generated, SWAT is ready to do simulation. The simulation period is from 1 January 2004 to 31 December 2005. The options are to get comparison between river discharge simulation and observed data. The rest of options available in the SWAT Running dialog box is presented in the last chapter. Several options must be considered; time step for rainfall and routing (daily), method for calculating runoff-Curve Number Method, rainfall distribution-skewed normal and method for evapotranspiration-Penman-Monteith.

The result of daily simulation and statistic comparison between observed data and un-calibrated simulation is presented in Figure 1. The result showed that simulation has lower base flow and higher peak flow in early year mainly on January 14th 2005. The linier correlation is not good enough (R^2 0.5351; $Q_{Simulation}$ = 0.9948 x Q_{Obs} -9.2574), where the value approaching 0.7 is much better. The Nash Sutchliffe efficiency (NSE) value is 0.411, which is far from the expected value.

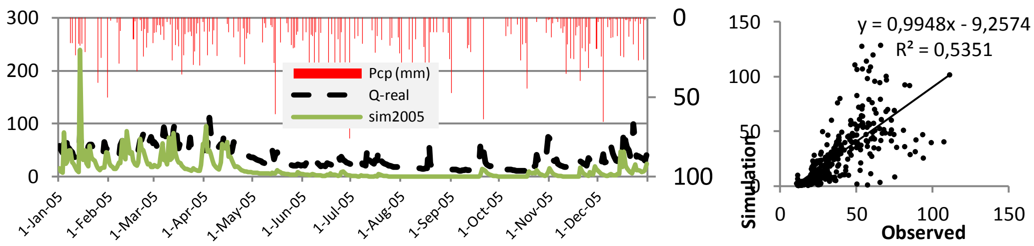

Figure 1. Simulation and observed measurement data comparison before calibration.

Table 3. Initial and final value of SWAT Calibration parameters for stream flow

SWAT variable name	Parameter	Range	Final value
SURLAG	Surface runoff coefficient	1 - 40	5
Alpha BF	Base flow alpha factor (days)	0 - 1	0.26
GW_Revap	Groundwater "revap" coefficient	0.02 – 0.2	0.02
REVAP_MN	Percolation to the deep aquifer to occur (mmH_2O)	0 - 500	10
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH_2O)	0 - 5000	800
GW-Delay	Groundwater delay (days)	0 - 500	31
SHALLST	Initial deep of water in shallow aquifer (mmH_2O)	0 - 1000	10
CH_N1	Manning's value for tributary stream	0 – 0.5	0.5
CH_N2	Manning's value for main stream	0 – 0.3	0.3
CH_K1	Effective hydraulic conductivity in tributary stream	0-300	0.5
CH_K2	Effective hydraulic conductivity in main stream		0.5
CN2	Curve Number	0 - 100	X 0.75
SOL_AWC	Available water capacity of the soil layer	0 - 1	X 4

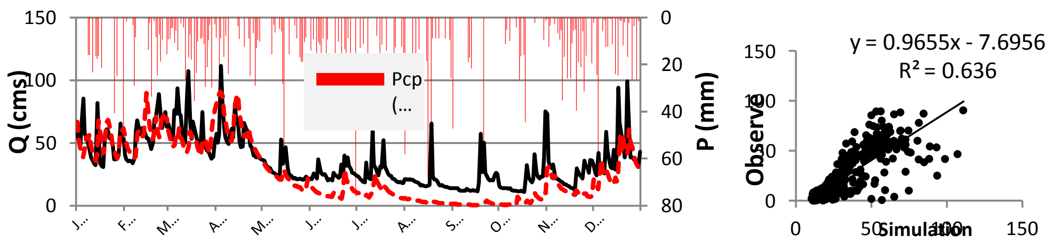

Figure 2. Discharge in Leuwidaun river gauge after calibration

Hydrology model was calibrated by comparison of observed to model and to adjust the key of hydrologic parameter. Based on the fact of hydrograph comparison the calibration focused on several solutions which are adjusted to infiltration, interflow and base flow recession parameter Manual calibration of several parameters resulted in correlation error (R^2) of 0.64 where $Q_{Obs} = 0.9655.Q_{Sim} – 7.6956$, and NSE is 0.495, the value of R^2 and NSE value is not good enough and the error is caused by un-detailed soil parameter. Details of adjustment for calibration are shown in Table 3, and result of discharge calibration in Leuwidaun river gauge is shown in Figure 2.

Landuse Change Impact to Hydrology Response

Landuse change analysis showed that more changes happened during 1991 to 2001, where the forest has been converted to other landuse class and settlement areas. The simulation was done by calibrated SWAT model based on 2005 climatic condition, where total precipitation is 2005 mm. This simulation resulted 15.32 mm for total surface runoff and 711.2 mm for total water yield. Those numbers can infer that catchment condition was much better than the simulated 2002 condition, where the value of surface runoff was 20.75 mm and total water yield was 718.8 mm. SWAT simulations in 1991 presented better catchment condition, where the value of surface runoff was 15.3 mm and water yield was 711.2 mm.

Table 4. Result of Water yield and surface runoff by SWAT simulation

Month	Precipitation 2005 (mm)	Water Yield (mm)			Surface Runoff (mm)		
		Landuse 1991	Landuse 2002	Landuse 2005	Landuse 1991	Landuse 2002	Landuse 2005
January	312	97.52	97.84	98.68	0.13	0.13	0.14
February	112	26.34	26.22	26.46	0.00	0.00	0.00
March	402	119.26	120.09	120.34	0.09	0.09	0.09
April	204	67.43	67.7	67.83	0.18	0.17	0.18
May	90	31.41	31.72	31.50	0.00	0.00	0.00
June	95	44.18	45.2	43.38	0.00	0.00	0.00
July	28	18.11	18.47	17.60	0.00	0.00	0.00
August	0	4.61	4.68	4.39	0.00	0.00	0.00
September	67	13.23	13.22	13.12	0.00	0.00	0.00
October	36	8.19	8.13	8.04	0.00	0.00	0.00
November	185	61.03	61.59	60.60	0.01	0.01	0.01
December	474	219.89	223.91	219.17	14.91	20.35	15.32
Average	167.08	59.27	59.90	59.26	1.28	1.73	1.31
Total	2005.00	711.20	718.77	711.11	15.32	20.75	15.74

Generally, SWAT simulation showed that the best condition of Upper Cimanuk Catchment Area based on landuse series is landuse of 1991. Landuse changes during the first period (1991-2002) were dominated by deforestation and urban growth. Deforestation, which has been done in mountain areas with steep slope and shallow soil depth, caused decrease of water percolation. In the second period (2002-2005) the condition of catchment was better as an impact of reforestation although urban growth still happened. Table 4 shows impact of different landuse series to water yield and surface runoff.

CONCLUSIONS AND RECOMMENDATION

Based on the result of study about SWAT and GIS application to address impact of landuse change on water availability and optimizing landuse in Upper Cimanuk Catchment Area, the general conclusions has been formulated. The population growth and economic development in Upper Cimanuk Catchment Area had an impact on landuse change and also on water availability. The general conclusions are as follows;

- During 1991-2005 most of the landuse change is caused by settlement area, mainly urban and sub-urban areas. The changes to settlement areas or urban growth usually occurred from conversion of agriculture, bare land, or grassland areas. Forest areas are converted to agriculture at steep slope area, mainly mountainous area. Mostly the landuse change is converting from good condition to poor condition from hydrology point of aspect.
- The SWAT Model can be used to find impact of landuse change to hydrology condition. The simulation of each landuse data series showed impact on landuse change on hydrology characteristics. The landuse change from 1991 to 2002 has indeed increased the surface runoff, while reforestation during 2002-2005 has decreased the surface runoff and increased base flow.

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