Analysis of the effect of land use changes on hydrology characteristics. Case study: the catchment area of Koto Panjang Hydroelectric Power

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Abstract. This study aims to analyze the hydrological characteristics as a result of changes in land use with the help of the SWAT hydrological model and can provide recommendations on the best land use in the Koto Panjang Electric Power catchment area. Based on the results of the analysis using the SWAT hydrological model, it was seen that there were effects of land use changes in 2011 and 2014 on hydrological characteristics; yield of water (WATER YLD) of 2,413.38 mm, and 1.008, 65 mm, runoff coefficient (C) of 0.19 and 0.063 respectively, and river regime coefficient (KRS) of 11.449 and 12.212, respectively. The best land use to be developed in agricultural cultivation areas as a recommendation to maintain water stability in the Koto Panjang hydropower catchment area is a simple and complex agroforestry pattern in scenario III, which is run together with hydrological characteristics in the form; water yield (WATER YLD) of 1,038.41, surface runoff coefficient (C) of 0.023, and river regime coefficient (KRS) of 11.13. The hydrological characteristics in scenario III are far better than 2014 land use characteristics (existing).

1 Introduction

Proper planning for land use is essential in improving the performance of a catchment area in maintaining water stability used for various interests, especially for the benefit of the wider community. Increased population growth affects land conversion, especially from forest areas to non-forest areas or cultivation areas.

The Koto Panjang hydropower catchment area is in three districts, namely, Kampar, Pasaman, and Lima Puluh Kota. Quoting from the Central Statistics Bureau of Pasaman Regency (2016), Pasaman Regency was dominated by Mapat Tunggul Selatan District with a population growth of 1.56%. Based on the Central Statistics Bureau of Lima Puluh Kota

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Regency (2016), Lima Puluh Kota Regency was dominated by Kapur IX Subdistrict with a population growth of 1.02%, Bukik Barisan District with a population growth of 0.85%, and Pangkalan Koto Baru District with the increase of 0.82%. From the data sources of the Central Statistics Agency of Kampar Regency (2016), it was noted that in Kampar District there were two subdistricts in the catchment area, namely XIII Koto Kampar District with a population growth of 1.48%, and Koto Kampar Hulu Subdistrict with a population growth of 3.81%. Population growth which tends to increase causes the ongoing development process is also very fast, causing changes in land use patterns, where the built space increasingly dominates and urges natural space to change functions [1].

Changes in land use due to an increase in population affect the hydrology characteristics of the watershed [2]. The results of the interpretation of Landsat images in 2002 land cover of forest in the catchment area 1,167.08 km [3]. According to [4] throughout eight-year forest cover experienced a significant change to 904,327 km, mainly changed to cultivated crops and open land. The extent of open land or deforestation can accelerate the flow of water to the reservoir and also affect fluctuations that affect the level of the reservoir water level.

The hydrological model of the Soil and Water Assessment Tool (SWAT) can help simulate the effects of land use changes on hydrological characteristics in producing water. According to [5] SWAT which is connected to GIS and integrates with Decision Support System (DSS). [6] said the SWAT model could analyze the best hydrological response based on the determination of conservation techniques. [7] said, the method used for calibration and validation using SUFI-2 and GLUE from SWAT CUP.

The purpose of this study is to analyze the hydrological characteristics due to changes in land use and can provide recommendations on the best land use in the catchment area of Koto Panjang Hydroelectric power.

2 Methodology

This research was conducted in the water catchment area of Koto Panjang Hydroelectric Power Plant, in West Sumatra Province consisting of Pasaman District in Mapat Tunggul Selatan District, Lima Puluh Kota District in Kapur IX Subdistrict, Bukit Barisan and Pangkalan Koto Baru, in Riau Province within Kampar Regency consisting of Koto Kampar Hulu Subdistrict and XIII Koto Kampar subdistrict.

Equipment needed is soil sample testing equipment, GPS devices, computer devices, GIS software, SWAT consisting of ArcSWAT and SWAT CUP SUFI 2.

The source of the research data consisted of Land use maps 2014, Image of Shuttle Radar Topography Mission (STRM) 30x30m for Digital Elevation Model (DEM) data input with scene numbers are ASTGTM2_N00E100 and ASTGTM2_S01E100, Administrative maps of Kampar, Pasaman, and Lima Puluh Kota year 2008, land use maps the year 2014, maps of the river, map soil type, slope class map, climate data (consisting of temperature, relative humidity, wind, and solar radiation, rainfall data) year 2009-2014, discharge data and water level of in the Koto Panjang Hydroelectric power catchment area year 2009-2014.

Several management scenarios in land use were simulated to determine the best land use management in the catchment area of Koto Panjang Hydroelectric power. Stages of activities consisting of collecting maps data, processing data input, and running SWAT models, calibration and validation, outputs and land use management simulations. Collection of Maps and Data consisting of; soil type map, land use map in 2011 and 2014 results of image interpretation, slope class of land map, Digital Elevation Model (DEM), physical properties data of soil from laboratory analysis based on soil samples in the catchment area, climate data, and river maps.

Input data processing consisting of; Watershed Delineator delineated based on input data in the form of DEM data, Hydrology Response Unit (HRU) analysis based on land use maps input data, slope class maps, soil type maps, and physical properties data of soil tests. Climate database (Weather Data Generator) by creating climate generator data results from the calculation of rainfall data, temperature, solar radiation, humidity, and wind speed.

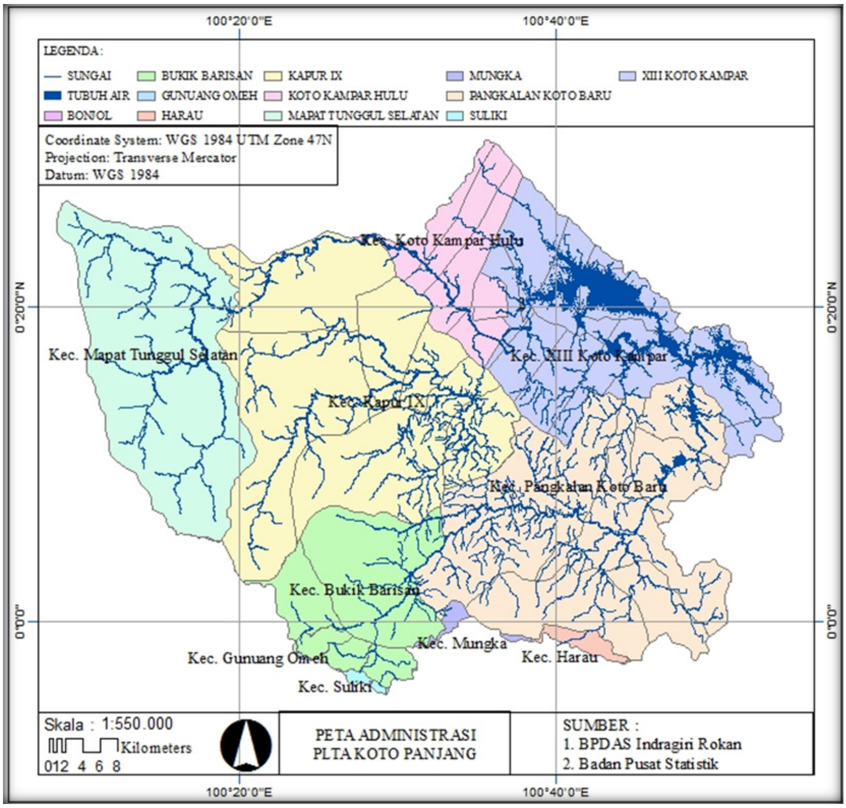

Fig. 1. The catchment area of Koto Panjang hydroelectric power.

The method of running the SWAT Model is to describe the catchment area (Watershed Delineator) with a stage consisting of entering DEM data, determining the river network, determining the catch outlet points, and calculating catch parameters. Conduct HRU (Hydrology Respect Unit) analysis in the form of defining data input with an overlay between the year 2011 and 2014 land use maps with land maps, and slope classes. Providing climate data other than rain for calculating evapotranspiration using sampling methods in the form of air temperature, air humidity, solar radiation and wind speed year 2009-2014 which must be provided in the SWAT model. SWAT simulations are carried out by selecting a heating time of 2 years from 1 January year 2009 to 31 December year 2010, which will be simulated in the Run SWAT menu for land use year 2011 and 2014. The output data storage from the simulation results is done by selecting the ReadSWAT Output sub-menu.

Calibration is a process of adjusting the combination of parameter values that affect the hydrological conditions of on SWAT CUP SUFI 2, in obtaining the results of the model that approaches the measurement results. Field measurement discharge data (discharge of observation) was used, namely the period of January 1, 2011, to December 31, 2012, with land use in 2011. The calibration method used in the study was the manual method with trial and error. The calibration procedure follows [8]. Statistical analysis used in calibration and validation is Nash Sutcliffe (NS) coefficient, and determination coefficient (R^2): Nash Sutcliffe (NS) coefficient,

$$NS = 1 - \left[\frac{\sum_i (Q_{si} - Q_{mi})^2}{\sum_i (Q_{si} - \overline{Q}_{mi})^2} \right] \tag{1}$$

where NS = Nash Sutcliffe coefficient, Q_{S1} = observation variable (actual discharge), Q_m = simulation result variable (model discharge), $\bar{Q}$ = average variable (average measured discharge). Nash Sutcliffe (NS) coefficient according to [9] consists of 4 classes: Very good, if 0.75 ≤ 1.00, Good, if 0.65 < NS ≤ 0.75, Satisfactory, if 0.50 < NS ≤ 0.65, and less satisfactory if, NS < 0.50. Determination coefficient (R^2):

$$R^2 = \frac{\left[\sum_i (Q_{mi} - \overline{Q}_m)(Q_{si} - \overline{Q}_{si})\right]^2}{\left[(Q_{mi} - \overline{Q}_m)^2 (Q_{si} - \overline{Q}_s)^2\right]} \tag{2}$$

where Q_{mi} = observation variable (actual measured discharge), $\bar{Q}_m$ = average observation variable (measured average actual discharge), Q_{si} = model calculation variable (simulation output discharge), $\bar{Q}_s$ = the average model calculation variable (simulation result discharge), with an R^2 value between 0-1 [10].

Validation aims to prove the consistency of the results of the SWAT model with measurement discharge data in another period, in this case, the discharge data from January 1, 2013, to December 31, 2014, with land use year 2014. The parameter values used in the validation process are the same as the parameter values in the calibration process. Further validation is carried out for each planned land use management scenario.

Analysis of hydrological characteristics due to changes in land use is based on land use data in 2011 and 2014. Very important hydrological characteristics can be known in the form of Water Yield abbreviated WATER YLD is the amount of surface flow (Qsurf), lateral flow (Qlat), and base flow (Qgw) [8] where the Qsurf is runoff water that flows above the soil surface of each HRU. The Qlat is water in the soil profile in the lateral direction that enters the reservoir within a specified period. Whereas the base Qgw is the flow in the shallow aquifer that enters the reservoir in the dry season.

To improve the hydrological characteristics in increasing the water yield in the catchment area of Koto Panjang Hydroelectric power is to create a land use planning scenario as below; 1. Applying a simple agroforestry pattern to agricultural cultivation areas (scenario I); 2. Applying complex agroforestry patterns to agricultural land areas (scenario II), and 3. Using simple patterns and complex agroforestry to agricultural land areas (scenario III) so that the hydrological characteristics for each scenario are analyzed Qsurf, Qlat, and Qgw in producing a better river WATER YLD.

3 Results and discussion

3.1 Analysis of changes in land use to hydrological characteristics

HRU analysis in the delineation process of the catchment area is based on three maps, namely land use map, slope class, and soil type, land use and soil characteristics based on soil physical properties. Soil data is data from the results of laboratory tests of the physical properties of soil samples from the catchment area by the Riau Laboratory of Soil. HRU analysis is carried out automatically by the SWAT program to produce a form of 60 HRU.

Every HRU that is formed will produce hydrological characteristics following the characteristics of each HRU. All hydrological characteristics of HRU that have been formed with land use year and climate data for the year 2011-2012 with SWAT model simulations resulted in coefficients R^2 is 0.67 and NS is 0.59 before the calibration parameter input was in a pretty good category. However, to get a better R^2 and NS value it needs to be calibrated.

3.1.1Calibration

Tabel 1. Absolute parameter that influence the R^2 and NS values using SWAT-CUP SUFI 2.

Parameter	**Note**	**Fitted Value**	**Range**	**Unit**
CN2 ALPHA_BF	(SCS Curve Number) Type of land use based on soil hydrology group Basic flow alpha factor	36.37 0.67	35-98 0-1	- day
GW_DELAY	Groundwater recharging time	43.30	0-500	day
GWQMN	The depth of the shallow aquifer threshold is needed	321.68	0-5000	mm (H_2O)
GW_REVAP	Groundwater evaporation coefficient	0.09	0.02-0.2	-
ESCO	The factor of change in soil evaporation	0.16	0-1	-
CH_N2	Manning roughness values on the main channel	0,03	-0.01-0.3	-
CH_K2	Conductivity on the main channel	254.69	-0.01-500	mm/jam
ALPHA_BNK	asic flow factor for storage	0.16	0-1	day
SOL_AWC	Water capacity is available in the soil layer	0.73	0-1	mm (H_2O)/mm soil
SOL_K	Hydraulic conductivity is saturated	254.13	0-200	mm/jam
SOL_BD	Density of soil type	0.89	0.9-2.5	g/cm^3
SURLAG	The surface flow pause coefficient	4.16	0.05-24	day
USLE_P	USLE land management factor	0.38	1-1	-
SLSUBBSN	Long slope of surface flow	30.14	10-150	m

The calibration process uses SWAT CUP SUFI 2 with observation data year 2011-2012. The parameters manually input by obtaining 15 adjustable parameters consisting of 11 most sensitive parameters and 4 less sensitive parameters as in Table 1. [2] get 13 parameters that can be changed are CN2, ALPHA_BF, GW_DELAY, GWQMN, RCHRG_DP, ESCO, EPCO, CH_N2, CH_K2, SOL_K, SOL_AWC, and SURLAG.

The results of the calibration process get the R^2 coefficient is 0.701, NS eficiensy is 0.75. NS eficiensy of 0.75 is good classified ($0.65 \leq NS \leq 0.75$) based on [9]. Hydrological characteristics for all HRUs formed after the calibration process based on climate data and discharge observations year 2011-2012 with land use year 2011 with the highest discharge of Qmax is 521,70 m^3/sec and the Qmin is 43.61 m^3/sec. The amount of PREC is 3,387.24 mm, Qsurf is 644.19 mm with WATER YLD in the catchment area is 2,413.38 mm so it is obtained the surface flow C coefficient is 0.19 classified of good according to Pramono (2014) [11], KRS coefficient of catchment area is 11.949 < 50 classified of good in accordance with [11].

3.1.2 Validation

The validation process aims to test the results of the calibration to other circumstances uses SWAT CUP SUFI 2 with the observation discharge data used is the period of January 1, 2013, to December 31, 2014, with land use year 2014 using the same parameters as the process of calibration. This validation process gets the R^2 coefficient of 0.64, NS efficiency value is 0.60. The value of NS efficiency is 0.60 in satisfactory classified ($0.50 < NS \leq 0.65$) according to [9].

3.1.3 Changes in land use

Changes in land use that occurred between the year 2011 and 2014 in the Koto Panjang hydropower of catchment area presented in Table 2. Land conversion between the year 2011 and 2014 in the form of a decrease in the primary dryland forest area is 7,137.92 ha, and Secondary dryland forest is 2,528.25 ha, the broad decline in Mixed dryland agriculture is 74.61 ha, and shrubs is 990.72 ha and As a result, there was an increase in the area of Plantation is 1,183.56 ha, Residential area is 1,069.83 ha, Dryland agriculture to be 6,730.71 ha, and Open land is 1,828.37 ha. In 2014 the remaining forest area was 142,160.07 ha (44.43%) > 30% as required by Law Number 41 year 1999. Better than when compared to [12] forest area in the Lake Toba catchment area only 23.83% and [13] the extent of the Way Besay watershed forest area is only 13.60%.

Show an increase in WATER YLD, where WATER YLD year 2011 is 2,413.38 mm while the WATER YLD was much smaller is 1,008.63 mm. This happened because of the difference in rainfall which was too large between the year 2011 amounting to 3,387.24 mm, surface flow is 644.19 mm, Qlat is 1,489.92 mm, with C coefficient is 0.19. When compared with the small amount of PREC in 2014, only 1,625.00 mm, the small amount of rainfall causes the soil layer to absorb water on a large scale, where only a small portion of the Qsurf is 102.12 mm and partly flow into the ground as Qlat is 821.25 mm and base flow Qgw is 80.27 mm, so that C coefficient shows a decrease with a value is 0.063. The small C coefficient in 2014 could be the primary cause is the small amount of PREC that occurred in that year. Hydrological characteristics as the effect of land use changes are presented in Table 3.

The surfce runoff coefficient obtained for land use year 2011 is 0.19 and land use year 2014 is 0.063 was still in line and better than [2] with coefficient C is 0.31 in the period year 2001-2006 classified as moderate ($0.25 \leq C \leq 0.50$) and the period of year 2006-2010 was good ($C < 0.25$). Different [14] surface runoff coefficient value C of 0.43 in the period year 1999-2003 and 0.43 in the period year 2004-2011 classified as moderate ($0.25 \leq C \leq 0.50$).

Tabel 2. Landuse in catchment area of Kotopanjang hydroelectric power.

Land use	Area 2011		Area 2014		Change	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Primary dryland forest	81,633.71	25.56	74,495.79	23.28	-7,137.92	-2.28
Secondary dryland forest	70,192.53	21.98	67,664.27	21.15	-2,528.25	-0.83
Plantation	10,756.74	3.37	11,940.30	3.73	1,183.56	0.36
Residential area	948.13	0.30	2,017.96	0.63	1,069.83	0.33
Dry land agriculture	78,149.88	24.47	84,880.59	26.53	6,730.71	2.06
Mixed dry land agriculture	72,877.65	22.82	71,886.93	22.47	-990.72	-0.35
Rice fields	3,502.80	1.10	4,042.19	1.26	539.38	0.17
Shrubs	360.79	0.11	286.17	0.09	-74.61	-0.02
Open land	916.89	0.29	2,745.26	0.86	1,828.37	0.57
Water body	10,984.33		10,363.97		-620.36	
Land area	319,339.12	100.00	319,959.48	100.00	620.36	0.00
Catchment area	330,323.45		330,323.45		0.00	

Tabel 3. Hydrological characteristics in catchment area of Kotopanjang hydroelectric power.

Hydrograph component	Hydrological characteristics	
	2011	2014
Surface runoff (Qsurf) (mm)	644.19	102.12
Interflow (Qlat) (mm)	1,489.92	821.65
Base flow (Qgw) (mm)	264.81	80.57
Water yield (mm)	2,413.38	1,008.63
Coefficient of surface runoff (C)	0.190	0.063
Coefficient of river regim (KRS)	11.949	12.212

According to [15], if the ratio of maximum discharge to the minimum has a small value, it means that the flow of water occurs throughout the year, in other words, the ability of the soil to enter and exit water is still quite good. The Qmak and Qmin simulation (model) occurred at land use year 2011 respectively 521.70 m^3/sec and 43.61 m^3/sec with a KRS value is 11.949. For land use year 2014 the Qmak and Qmin simulation (model) respectively 521.70 m^3/sec and 42.72 m^3/sec with a KRS value are 12.212. The KRS value for land use year 2011, and 2014 respectively 11.949 and 12.212 <5 0, based on the classification by [11] as proper classification. With the value of the PRC year 2011 and

2014 were still relatively good it can be said that in one month for the entire year the flow of water flowing in controlled fluctuations.

The KRS value obtained is smaller and better than KRS value from the results of [14], in the period year 1999-2011 the PRC value in the Ciujung watershed was between 83-163 (while was bad), and [2] the KRS values in the Way Betung watershed year 2001, 2006 and 2010 were 30.65, 66.25, and 53.57 respectively (good-medium) and [15] with the KRS values in the Serang watershed in 2004-2007 between 69-200 (while-bad).

Based on the primary and secondary dryland forest area, the remaining 44.33% > 30% as required, and in line with KRS that are still relatively good, the most appropriate step to take is to make the cultivation area this agriculture can approach forest functions. Thus, it can minimize the flow of surfaces that enter the river so that the falling rainfall can be absorbed mostly as lateral flow, and the basic flow and finally produce a stable Water Yield. To maintain agricultural cultivation can approach forest functions is to manage agricultural cultivation areas with the application of agroforestry patterns.

3.2 Effect of land change on hydrological characteristics

According to [16], agroforestry is also a land use system that is carried out with various technologies through the use of annual crops, annual crops, and/or livestock at the same time or taking turns in certain periods so that ecological, social and economic interactions are formed. This system is more advantageous than other land use systems.

Tabel 4. Hydrological characteristics in catchment area of Koto Panjang hydroelectric power plant 2014 at scenario.

Hydrograph compenent	**Hydrological characteristics**			
	First scenario	**Second scenario**	**Third scenario**	**Existing**
Surface runoff (Qsurf) (mm)	54.32	88.46	37.20	102.12
Interflow (Qlat) (mm)	839.50	825.61	885.30	821.65
Baseflow (Qgw) (mm)	101.56	85.13	110.06	80.57
Water yield (mm)	1,000.69	1,003.68	1,038.41	1,008.63
Coefficient of surface runoff (C)	0.033	0.050	0.023	0.063

Land use management with agroforestry patterns is planned in the form of simple and complex agroforestry in agricultural cultivation areas which are simulated using the SWAT hydrological model in three scenarios namely: scenario I simple agroforestry is planned in dryland agriculture, plantations, rice fields, open land with a land area is 103,608.34 ha (32.38%) of the land area of the catchment area; scenario II complex agroforestry is planned in dryland agriculture mixed with shrubs, shrubs with an area is 72,273.11 ha (22.56%) of the land area of the catchment area; scenario III simple agroforestry and complex agroforestry on scenario I and II is 175,881.45 ha (54.94%) of the land area of the catchment area. The Hydrological characteristics of results the SWAT model scenario of the management of the use of agricultural cultivation areas with a simple and complex agroforestry pattern in the Koto Panjang Hydroelectric power plant catchment area are presented in Table 4. While the KRS value based on the maximum and minimum discharge by carrying out the scenario I - III is shown in Table 5.

Tabel 5. River regim coefficient (KRS) in each scenario at 2014.

Type of land use	Qmax	Qmin	KRS
	(m^3/s)	(m^3/s)	(Qmax/Qmin)
Land use in 2014 (existing)	532.2	44.07	12.212
I (Simple agroforestry)	512.80	43.55	11.775
II (Complex agroforestry)	512.55	44.08	11.628
III (Simple + Complex agroforestry)	523.90	47.07	11.130

In scenario I with a simple agroforestry pattern by simulating together with other land uses in the catchment area, the results show Qsurf is 54.32 mm < QSurf of land use year 2014 (existing) is 102.12 mm, this indicates that rainfall that has fallen can be absorbed in the form of Qlat is 839.50 mm > Qlat (existing) is 821.65 mm and the Qgw is 101.56 mm > Qgw (existing) of 80.57 mm, but WATER YLD is 1.000,69 < WATER YLD (existing) of 1,008.63 mm. From the decrease in the value, Qsurf also affects reducing C is 0.033 < C (existing) of 0.063. The KRS in the scenario I get the KRS value 11.775 < KRS (existing) of 12.212 as contained in Table 5. This shows more stable water flow that occurs throughout the year. Of the several aspects that are generally reviewed, the land use hydrological characteristics in the scenario I are slightly better than the land use year 2014 (existing) with a note that only amount of WATER YLD obtained is somewhat smaller than the land use year 2014 (existing).

Scenario II with complex agroforestry patterns that are simulated simultaneously with other land uses in the catchment area, shows Qsurf is 88.64 mm < Qsurf (existing) is 102.12. Rainfall that falls far more into the absorbing surface of the land in the form of Qlat is 825.61 mm > Qlat (existing) is 821.65 mm and the Qgw is 85.13 mm > Qgw (existing) is 80.57 mm. The WATER YLD is 1,003, 68 is also < WATER YLD (existing) is 1,008.63 mm. Decreasing that occurs in the value of the Qsurf has an impact on the decrease in C is 0.5 a little smaller than the value of C is 0.033 in the scenario I or C is 0.063 (existing). The KRS in scenario II is 11.628 < from the KRS scenario I is 11.775 and The KRS(existing) is 12.212, meaning that the drainage of water flow in scenario II in the catchment area throughout the year is more stable than scenario I. This means the simulation results on the scenario II is slightly better than land use in scenario I.

Scenario III which is a combination of simple agroforescence patterns of complexes that are carried out simultaneously with other types of land use in the catchment area, gives a Qsurf is 37.20 mm shows better results because < Qsurf scenario I is 54.32 and scenario II is 88.46 or Qsurf (existing) is 102.12 Rainfall falls far more into the soil surface until it is absorbed in the form of Qlat is 885.30 mm > Qlat (existing) is 821.65 mm and Qgw is 110.06 mm > Qgw (existing) is 80.57 mm, WATER YLD is 1,038.41 also > WATER YLD of scenario I is 1.000.69, WATER YLD of scenario II is 1,003.68, and WATER YLD (existing) is 1,008.63 mm. The KRS for scenario III is 11.13 < KRS of scenario I is 11.775, KRS scenario II is 11.662, and KRS (existing) is 12.076, this means that the flow of water in scenario III in the catchment area throughout the year is much more stable than the scenarios I and II so that, planning for use in scenario III is better to carry out because it is better than land use in Scenario I and II.

4 Conclusions

The results of a study as follows. The best characteristics of the three land cover planning scenarios are, water yield (WATER YLD) is 1,038.41 mm, runoff coefficient (C) is 0.023 and river regime coefficient (KRS) is 11.13. The land cover model recommended in the Kotopanjang hydropower catchment is scenario III (simple and complex agroforestry pattern).

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