The Changes of Land Use Pattern Affect to the Availability of Water Resources in Siak Watershed, Riau Province, Indonesia

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Abstract. Significant shift in the land use within Siak watershed (DAS Siak) affects to its availability of water resources. This also affected to increase fluctuation level of the river flows. Therefore to develop a comprehensive watershed management strategies, it is required a hydrological model which is in capable to represent the hydrological cycle of the watershed. Hydrological model may use the Soil and Water Assessment Tool (SWAT) application software package. The SWAT simulations performed various scenarios for land use changes in the period of 2002, 2007, and 2012 within the Siak watershed. Based on this research study, the optimal determination coefficient (R^2) of SWAT output models were = 0.59, with Nash-Sutcliffe Efficiency (NSE) was 0.58. These results have satisfied the research objectives as the findings coefficient > R^2 min (0.4), and NES min (>0.36). The level of water resources availability was calculated by comparing the ratio of Qmax and Qmin of the Siak flow during the period of 2002 to 2012. It was revealed that the ratio of water resources (Qmax/Qmin) were as the following order 10.72 (2002), 6.83 (2007) and 12.95(2012) respectively. Should the ratio value Qmax/Qmin was higher, the more critical the condition of Siak water resources will be. Hence, the changes in land use in the Siak watershed affected to suppress the water resources.

Introduction

An intensive land use pattern changes within a watershed may affect to hydrological cycle (Arsyad, 2006). An intensive land clearing activities for developing palm oil plantation, agricultural land, and settlement have became very common happened since 30 years ago within this SIAK watershed. Low water infiltration rate causes to increase of surface river water flow rate. As the consequences the fluctuation of water level within Siak River even higher.

Based on the basic river flow data obtained from the Automatic Water Level Records , AWLR installed in the Siak River Bridge. It was recorded that the maximum river water level tends to increase in the period of 1998 to 2005. The minimum river water level tends to become lower. As the result of high difference level between the maximum and minimum of Siak water surface, flood cases (during the rainy season) and drought (during the summer) became more frequently. This indicates the availability of water resources also tends to decrease (Purbawa and Wirajaya, 2009, and Triatmodjo, 2010).

One of the common methods used to determine the availability of water resources in a watershed is by comparing the value of Qmax/Qmin of river water flow during a certain period.

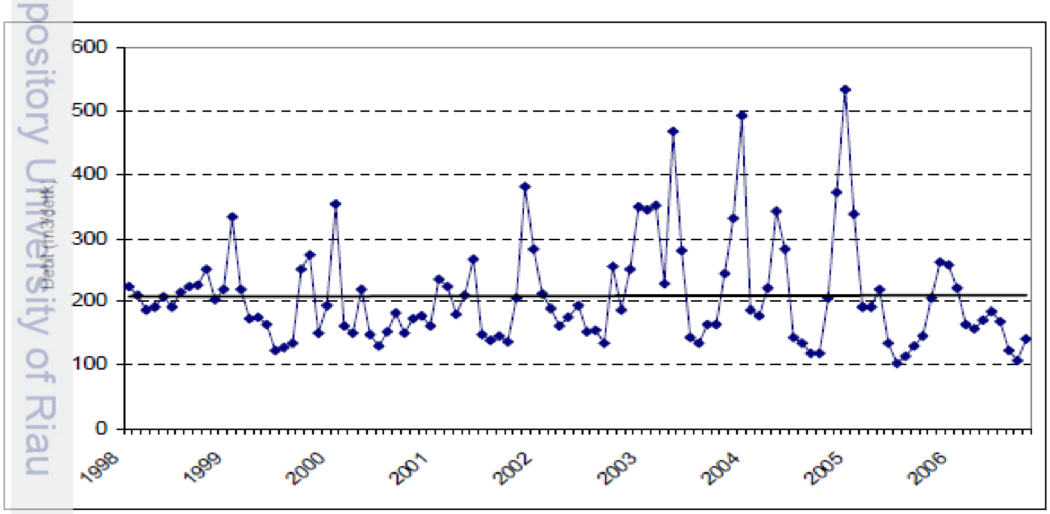


Fig. 1. Average Monthly Debit (m^3/sec) of the Siak River 1998-2006.

A hydrological model that is able to represent a watershed hydrologic cycle. This study used a model generated from the Soil and Water Assessment Tool (SWAT). SWAT is a tool to simulate the effects of land use change in relevance to calculate an availability of water resources in the watershed.

The objectives of this study are to: (i) identify the magnitude of changes in land use pattern within watershed Siak area in the year of 2002 , 2007 and 2012, and (ii) simulate the effects of land use change correlating to water resources availability in this watershed. This study results are expected to become a reference for stakeholders especially the Indonesia government to take any water conservation policy for Siak River water resources systematically.

Methodology

This study was commenced in the Siak watershed utilizing AWLR data from the Pantai Cermin. Weather Station located in the Riau Province, with position of 00° 35’ 24” SL and 101° 11’ 46” EL.

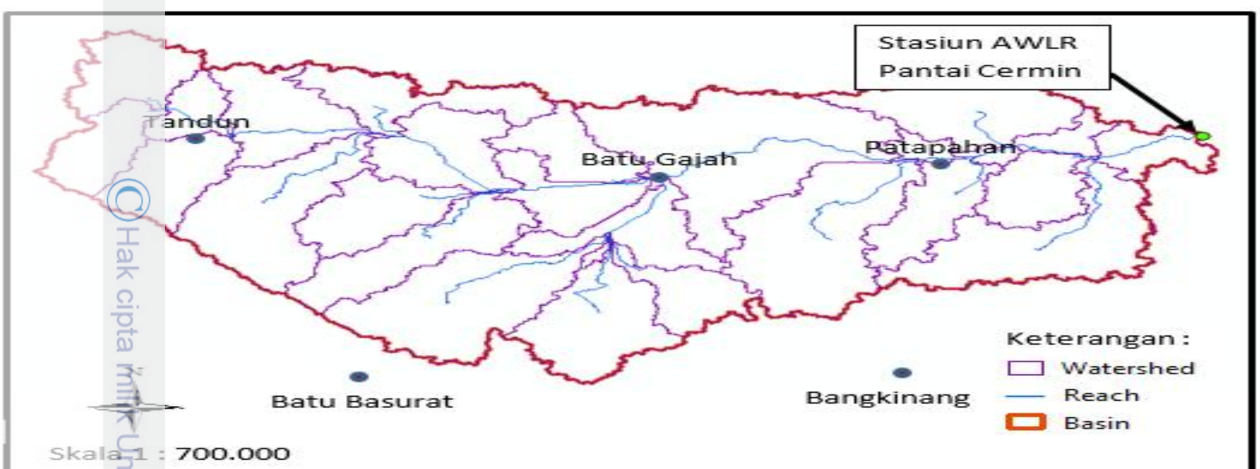


Fig 2. Map Location
(Source : BWS III Riau Province)

Various input data required to simulate SWAT model including climate data, digital elevation maps (DEM), land use maps, and soil data. SWAT generated a series of models that can provide hydrological response as an output. The output then was calibrated and validated in order to achieve a satisfied level of accuracy compared to the existing data recorded in AWLR (Tables 1 and 2).

The statistical methods used to validate by calculating coefficient of determination (R2) and the Nash - Sutcliffe efficiency model (NS).

$$R^2 = \frac{[\sum_i (Qobs,i - \bar{Q}obs,i)(Qcal,i - \bar{Q}cal,i)]^2}{\sum_i (Qobs,i - \bar{Q}obs,i)^2 \sum_i (Qcal,i - \bar{Q}cal,i)^2} \quad (1)$$

$$NS = 1 - \left[\frac{\sum_{i=1}^{n} (Q_{obs,i} - \bar{Q}_{cal,i})^2}{\sum_{i=1}^{n} (Q_{obs,i} - \bar{Q}_{obs,i})^2}\right] \quad (2)$$

Determination coefficient criteria were defined as the following table.

Table 1. Criteria of Determination coefficient

R^2 Value	Interpretation
$0,7 < R^2 < 1,0$	High impacts
$0,4 < R^2 < 0,7$	Medium impacts
$0,2 < R^2 < 0,4$	Low impacts
$R^2 < 0,2$	No impacts

(Source: Hambali,2008)

Motovilov *et al* (1999), recommended *Nash-Sutcliffe Efficiency (NSE)* as the following table.

Table 2. *Nash-Sutcliffe Efficiency (NSE) criteria*

NSE	Interpretation
NSE > 0,75	Good
0,36 < NSE < 0,75	Moderate
NSE < 0,36	Low

(Source : Motovilov, *et al* 1999)

The calibration process is the process of selecting a combination of parameters to improve the coherence between the hydrologic responses observed with the simulation results. The validation process on the other hand, is to prove whether the simulation process is consistent with the established specifications (NSE).

Land Use Change in SIAK Watershed

An undergone of significant changes in land use within SIAK watershed was based on data analyzed from the satellite images. The signficant shift in land use can be seen in Table 3.

Table 3 shows that the primary forest area decreased 4.86 % from 15,624.36 ha (in 2002) to 7,352.64 ha (in 2007). The forest area then increased again to 12,186.32 ha in 2012. This figure was still lower than those forest areas in 2002 (-2.02 %).

In 2002 the oil palm plantation area covered 76,249.60 ha and this figure tended to increase to 7,9347.24 ha in 2012 (by 1,82%).

Table 3. An ongoing of land use changes in period of 2002, 2007 and 2012.

Land Use	2002		2007		2012	
	Area (ha)	Percentage (%)	Area (ha)	The magnitude of changes compared to 2002 (%)	Area (ha)	The magnitude of changes compared to 2002 (%)
Primary Forest	15624,36	9.18	7352,64	-4,86	12186,32	-22%
Industry Forest Plantation (HPH)	17054,04	10.02	20117,64	1,8	12441,62	-27%
Rubber plantation	4084,80	2,40	5514,48	0,84	3914,60	-4%
Oil Palm Plantation	76249,60	44,80	75960,26	-0,17	79347,24	4%
Settlement	1310,54	0,77	1106,30	-0,12	3386,98	158%
Water area	17,02	0,01	17,02	0,00	17,02	0%
Agriculture	41937,28	24,64	47366,66	3,19	41188,40	-2%
Bushes	11369,36	6,68	6416,54	-2,91	13939,38	23%
Open space	2553,00	1,50	6331,44	2,22	3778,44	48%
Total	170200	100	170200		170200	

Source : Analysis, 2014

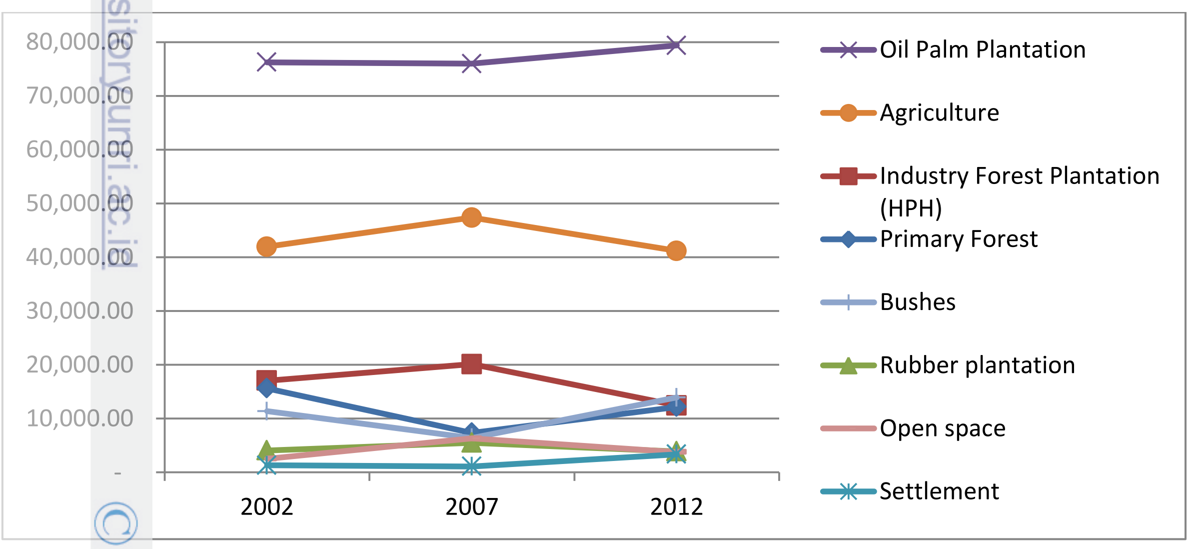
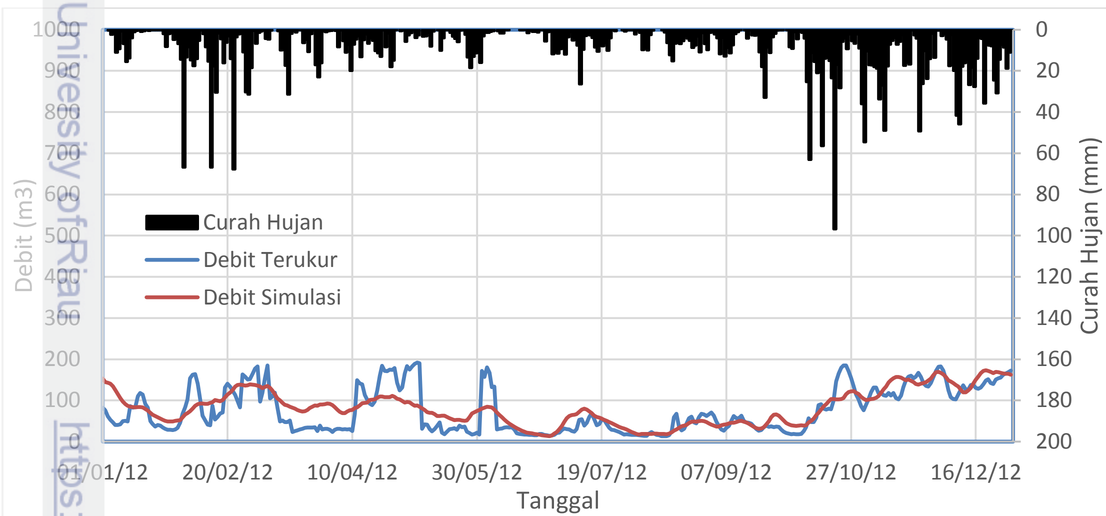


Fig 3. An ongoing of land use changes in period of 2002, 2007 and 2012.
(Source : Data Analyses, 2014)

Hydrology Modeling

Debit Analyses Based on Land Use 2012

At the beginning of the simulation, it was used the parameters specified by the SWAT or without calibration. The initial results from this early simulation commonly were still much different from the AWLR data. Hence, a calibration process is required. In 2012 calibration was performed 4 times with 1,000 iterations. Input data parameters were regularly adjusted until the validity value of R^2 was 0.59 (> 0.4) and NSE was 0.58 (>0.36).



Picture 5. Comparison of Hydrograph of AWLR data and SAWT Simulation model Year 2012 (after data Calibration). (Source : Data Analysis, 2014)

Tabel 5. Parameters and input values for calibrating 2012 land use models

No	Parameter	Fitted_Value
1	R__CN2.mgt	0,1162
2	V__ALPHA_BF.gw	0,3475
3	V__GW_DELAY.gw	64,33
4	V__GWQMN.gw	1507,5
5	V__REVAPMN.gw	107,25
6	V__RCHRG_DP.gw	0,1515
7	V__GW_REVAP.gw	0,17687
8	R__SOL_K(..).sol	10,13425
9	R__SOL_AWC(..).sol	7,39075
10	R__SOL_Z(..).sol	2,01475
11	V__CH_L1.sub	34,985
12	V__CH_S1.sub	3,1875
13	V__CH_K1.sub	216,75002
14	V__CH_W1.sub	888,61151
15	V__OV_N.hru	0,72143
16	V__EPCO.hru	0,5975
17	V__CANMX.hru	0,15
18	V__ESCO.hru	0,9685
19	V__SLSUBBSN.hru	20,15
20	V__HRU_SLP.hru	0,5343
21	V__SURLAG.bsn	11,3845
22	V__CH_K2.rte	348,75
23	V__CH_N2.rte	0,22266
24	V__ALPHA_BNK.rte	0,5845

(Source : Data Analysis, 2014)

Sensitivity Analysis

The sensitivity analysis performed to obtain an overview of the most significant parameters affecting the simulation SWAT. The results of the sensitivity analysis showed that there were 8 the most significant parameters influencing on the results of SWAT results. They were: (i) RCHRG_DP.gw (deep aquifer percolation friction as ground water recharge), (ii) hydrologic responses unit (HRU_SLP), (iii) initial SCS runoff curve number for moisture II (CN2), (iv) saturated hydraulic conductivity (SOL_K), (v) average slope length (SLSUBBSN), (vi) based flow alpha for bank storage contributing flow to main channel (ALPHA_BNK), (vii) threshold depth of water in shallow aquifer required for return flow to occur (GWQMN), and (viii) ground water "revap" coefficient, as water remove from the capillary fringe it is replaced by the water underlying aquifer (GW_REVAP),

The results of the sensitivity analysis are shown in Table 5. It is sequentially starting from the most sensitive based on the p-value. The smaller the p-value, the more significant of these parameters will be (notes: the smallest value is zero) (Neitsch et al . , 2002) .

Table 5. Sensitivity Analysis For the calibrated parameters

No	Parameter	*P-Value*	No	Parameter	*P-Value*
1	RCHRG_DP.gw	0.00	13	SOL_Z(..).sol	0.14
2	HRU_SLP.hru	0.00	14	CH_S1.sub	0.22
3	CN2.mgt	0.00	15	EPCO.hru	0.35
4	SOL_K(..).sol	0.00	16	CH_L1.sub	0.36
5	SLSUBBSN.hru	0.00	17	ESCO.hru	0.36
6	ALPHA_BNK.rte	0.00	18	REVAPMN.gw	0.41
7	GWQMN.gw	0.00	19	CANMX.hru	0.43
8	GW_REVAP.gw	0.00	20	CH_N2.rte	0.63
9	CH_K2.rte	0.01	21	CH_W1.sub	0.65
10	OV_N.hru	0.01	22	ALPHA_BF.gw	0.70
11	CH_K1.sub	0.08	23	SOL_AWC(..).sol	0.73
12	SURLAG.bsn	0.10	24	GW_DELAY.gw	0.99

(Source : Analysis, 2014)

Analysis of Availability of Water Resources

In this study, analysis of water resources within watershed of DAS Siak was calculated by comparing the value of Qmax / Qmin each period (started from 2002 to 2012). Qmax and Qmin values used to identify a trend of watershed change. If the ratio value of Qmax / Qmin higher, there is a tendency decreasing of water availability at the watershed. Table 6 is the ratio calculation Qmax / Qmin in the period of 2002, 2007 and 2012 .

Table 6 Qmax/Qmin Ratio

Year	Qmax	Qmin	Ratio of Qmax/Qmin
2002	162.8	15.18	10.72
2007	181.5	26.56	6.83
2012	172.9	13.35	12.95

(Source: Data Analysis, 2014)

From the above table it can be seen that the availability of water resources from 2002 to 2012 relatively fluctuated. However it tended to increase from 10.725 to 12.951 (an increase rate of

20%). This is due to the slightly changes in land use in the period of 2002 to 2012. It can be seen in Figure 8.

However, in period of 2002 to 2007 a decline in the value of the ratio of Qmax/Qmin from 10.72 to 6.83, this was due to: (i) a decrease of palm oil plantation area from 76,249 ha to 75.947 ha in the period of 2002 to 2007 (cutting old palm oil trees and replanting the new one), (ii) an increase in the industry forest plantation area of 17.054 ha to 12.441 ha, (iii) an increase in open space area from 2553 ha to 6331 ha, thus these may effect to reduce the amount of water runoff. Hence, the ratio of Qmax/Qmin tended to be better in 2002 to 2007 (from 10.72 to 6.83 respectively).

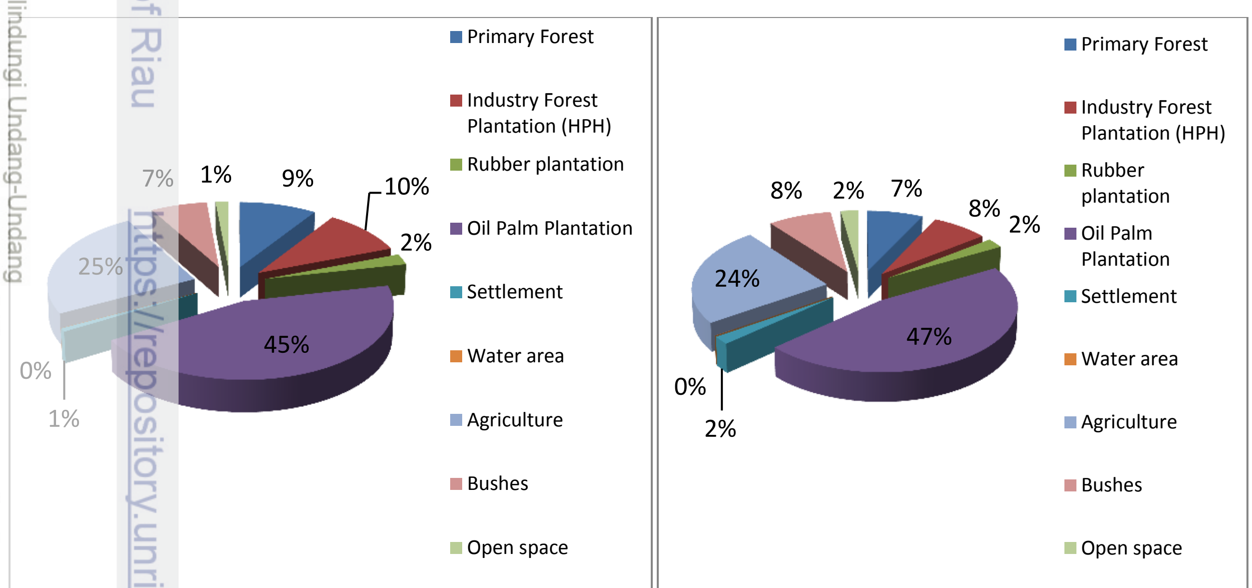


Fig. 5. Land use pattern 2002 to 2012.

In the period of 2007 to 2012 the value of ratio of Qmax/Qmin increase substantially from 10.72 to 12.95 (20%), this was due to: (i) an increase of palm oil plantation area from 76,249 ha to 79.347 ha (4%) in the period of 2002 to 2012), (ii) an increase in settlement area from 1310 ha to 3346 ha (158%), (iii) an increase of open space area by 48%, and bushes area 23%. The areas of primary forest as well as forest plantation were decreasing up to 22%. Thus these land use changes may effect to increase the amount of water runoff. Hence, the ratio of Qmax/Qmin tended to became worst (from 10.72 to 12.95), so the availability of water resources in the DAS Siak tends to decline.

D. CONCLUSIONS

. The significant change in land use patterns within Siak water shed in the period of 2002-2012 to become palm oil plantation area, settlement area, open space and bushes, meanwhile the forest area decreased causes the availability of water resources in the DAS Siak tends to decline. This was reflected by the ratio of Qmax / Qmin in 2002 to 2012 tended to decrease from 10,725 to 12,951 respectively. Based on SWAT simulation the final results showed that the value of R^2 was 0.59 (> 0.4) and NSE was 0.59 (>0.36). Hence, these values were satisfied the research objectives.

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