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RESEARCH ARTICLE

APPLICATION OF MATHEMATICAL MODEL FOR THE DILUTION OF WASTE WATER FROM LAND UTILIZATION IN THE UPPER THA CHIN WATERSHED, THAILAND

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ABSTRACT

The objective of this study was tomathematicalmodeling development for generating the water storage capacity necessary to dilute waste water from land utilization in the Upper Tha Chin Watershed (UTCW) within three scenarios: existing land use condition, expected land use change in the year 2020, and regulating water storage to dilute Biochemical Oxygen Demand (BOD). The Soil and Water Assessment Tool (SWAT) model was applied in order to estimate the amount of the streamflowand BOD based on the observed land use and water release data from the reservoir, from January, 2013 to December, 2014 as presented in Scenario 1. The reliability of the model was calibrated with the observed data by adjusting the coefficient of the key parameters through SWAT calibration uncertainty procedures (SWAT-CUP) and validating the observed data from seven hydrologic stations. The simulating the impact of land utilization in the year 2020 in Scenario 2, and the drainage simulation of the Krasiao reservoir on BOD in Scenario 3. The results obtained from the SWAT model found that in Scenario 1 indicated that the streamflow was 374.74 million cubic meter (MCM) and BOD was 2.70 mg/L. The simulation of Scenario 2, forecasting the expected land use change in year 2020, showed that the amount of the streamflow decreased to 65.09 MCMand BOD was 2.70 mg/L; when compared with Scenario 1. The simulation of Scenario 3, regulating water storage for diluting waste water, found that BOD during the dry season of December, January, February, and March was 3.08, 3.24, 1.52, and 2.70 mg/L, respectively; and a decrease to 1.50 mg/L with an increased drainage of the Krasiao reservoir. This study shows that the SWAT model successfully stimulated and assessed the effects of land use activities on streamflow, sediment, and BOD; including the successful drainage of the Krasiao reservoir in both watershed and sub-watershed areas.

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INTRODUCTION

As an important element in basic human life, water is a natural resource necessary for basic economic development; including agriculture, public utilities, and transportation, as well as diluting waste human activity. Thailand has been facing the problems of water shortages and water quality, mainly due to increasing populations and changing lifestyles; especially in the central region, where the resident population, economic expansion, and housing have increased rapidly. Without proper water management and planning or in the event of the reckless usage of limited water resources, water yields will be affected in terms of quantity, quality, and the flow timing; leading to the degradation and pollution of water resources.The UTCW, while having changed from its original condition, still provides a suitable ecosystem and environment. The land use or activities inside the watershed area rarely grows or expands. Water waste and pollution contamination entering the stream can be reconditioned or refreshed in equilibrium at certain levels. Current water quality problems are likely to continue to intensify and deteriorate, mainly due to human activities, such as the expansion of agricultural activities along the riparian river zones, including the encroachment of headwater for agricultural expansion. Such activities are the cause of soil erosion and pollution contamination of waste water, especially during the dry season flow, which induces the concentration of waste water greater than the carrying capacity. This directly and adversely effects water yields, in terms of quantity, quality, and timing of water flow to those people living along the river and surrounding areas. The problems and impacts of management related to the degradation of natural resources, especially in the field of water resources, are important to all living things, and have inspired the authors to study the water

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storage capacity for the dilution of waste water from land utilization in the UTCW. This study hopes to provide systematic and sustainable concepts which will help prevent the deterioration of water yield problems to the ecology and environment, as well as to establish the guidelines of limited water resources, including land use in the UTCW. The main objective of this study was to investigate the physical characteristics of watershedand application of mathematical model for generating the reservoir to dilute waste water from land utilization in the UTCW for suitable, systematic, and sustainable development.

MATERIALS AND METHODS

The location of UTCW is in the central Thailand, divided into 14 sub-watersheds and the location of the Krasiao reservoir in sub-watershed 8 (Figure. 1). The total watershed area is about 5,253.96 Km^2 and topography is a lowlands. Most of the land in the north, east and south of UTCW area is an agricultural area as rice fields and crops, the west part is the foothills and mostly covered with a deciduous forests and trees with elevations ranging from 2 to 1,538 m above mean sea level. The climate of the UTCW area in terms of annual rainfall, averages of humidity, and daily temperature observed during 2013 to 2014 are 1,115 mm, 72.80% and 28.9°C, respectively. According to Thai classification system, there are 32 soil groups and land use can be classified into 9 types.

(IRD), Pollution Control Department (PCD), and Thai Meteorological Department (TMD). The SWAT model and Geographic Information System (GIS) software were employed to simulate the hydrological characteristics and evaluate the impact of the land use activities affecting the amount of the streamflow and BOD within the UTCW.

Analysis and evaluation

The analysis and evaluation of the data were divided into two main parts as described below:

The data on streamflow and water quality (BOD) in the UTCW observed during January 2013 to December 2014 were analyzed in terms of mean monthly discharge and water quality (BOD) in each station or at measurement points to use as database in the verification/calibration of the assessment by the SWAT model. The calculation in the SWAT model is based on the premise that the simulation of the hydrology of a watershed can be separated into two major divisions. The first division is the land phase of the hydrologic cycle. The land phase of the hydrologic cycle controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-watershed. The second division is the water or routing phase of the hydrologic cycle, which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet (Neitsch*et al*., 2011).

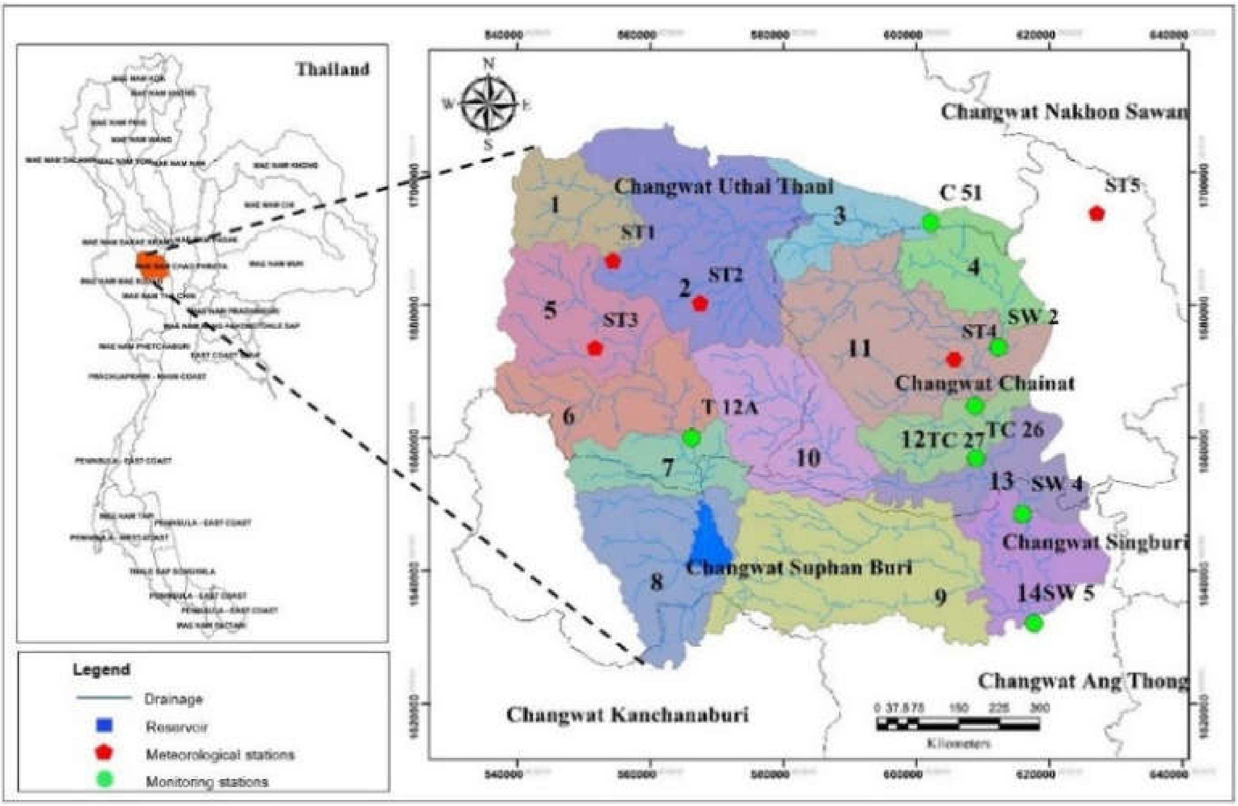


Figure 1. The location of the UTCW and 14 sub-watersheds

Data collection

The data used in this study to evaluate the amount of streamflow and BOD; including the digital elevation model (DEM), land use data, soil data, discharge data, BOD data, and meteorological data, were collected from the Land Development Department (LDD), Royal Irrigation Department

The land phase of the hydrologic cycle is modeled in the SWATmodel is based on the water balance as equation (1).

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad \ldots(1)$$

Where SW_t is the final soil water content (mm), SW_0 is the initial soil water content (mm), t is the time (days), R_{day} is the amount of precipitation on day (mm), Q_{surf} is the amount of surface runoff on day (mm), E_a is the amount of evapotranspiration on day (mm), W_{seep} is the amount of percolation and bypass flow exiting the soil profile bottom on day (mm), and Q_{gw} is the amount of return flow on day (mm).The carbonaceous biological oxygen demand (CBOD) defines the amount of oxygen required to decompose the organic matter transported in surface runoff and based on a relationship by Thomann and Mueller (1987) as equation (2).

$$cbod_{surq} = \frac{2.7 \cdot orgC_{surq}}{Q_{surf} \cdot area_{hru}} \quad ...(2)$$

Where $cbod_{surq}$ is the CBOD concentration surface runoff (mg CBOD/L), $orgC_{surq}$ is the organic carbon in surface runoff (kg *orgC*), Q_{surf} is the surface runoff on a given day (mm H_2O), $area_{hru}$ is the area of the HRU (km^2).

However, the SWAT model is a continuous time model that operates on a daily time step, spatially semi-distributed, physically based model (Arnold *et al*., 1998; Baker and Miller, 2013; Brzozowski*et al*., 2011; Uzeika*et al*., 2012; Strauch*et al*., 2012, 2013; Andrade *et al*., 2013; Pinto *et al*., 2013. In this study the surface runoff from daily rainfall was estimated using the modified SCS curve number (USDA-SCS, 1972). The peak runoff rate calculates with a modified rational method (Neitsch *et al*., 2011) and the lateral sub-surface flow calculates with a kinematic storage model (Sloan and Moore, 1984) and the potential evapotranspiration (PET) was determined by using the modified penman-monteith approach (Jensen *et al*., 1990). The basic file needed by the SWAT model were for delineating the watershed into sub-watershed and HRUs including the digital elevation model (DEM) was interpolated from topo to raster, the soil data, and the meteorological data for the UTCW during January 2013 to December 2014.

Verification and calibration of the SWAT model

The verification of the SWAT model uses data from the simulation results of the SWAT model with measurement data in the study area from monitoring stations or sampling points during January 2013 to December 2014. The calibration models using in this study is theautomatically using the SWAT calibration uncertainty procedures (SWAT-CUP) (Abbaspour *et al*., 2004; Abbaspour, 2007; Schuol*et al*., 2008; Yang *et al*., 2008; Oeurng *et al*., 2011; Arnold *et al*., 2012; Pinglot, 2012; Abbaspour *et al*., 2014), which is an automatic calibration and this method of calibration to appropriate coefficients results of the parameter before being used in the SWAT model. The criteria for calibration accuracy and appropriateness of the SWAT model uses a graph, coefficient of determination (R^2), nash-sutcliffe efficiency (NSE) and mean squared error (MSE).

The simulation of land use impact on streamflow and water quality (BOD)

After model verification and calibration, the model was applied to assess the land use change and its effects on streamflow and water quality (BOD). The results were used in the management planning for the UTCW including draining of the Krasiao reservoir storage to dilute waste water that caused by land utilization to figure out suitable and sustainable land use and water storage regulation. The simulations were made using three scenarios below:

Scenario 1: The land use at the existing condition in the UTCW during 2013 to 2014.This is a case of the existing condition of land use and water drained from Krasiao reservoir affecting on streamflow and water quality (BOD).

Scenario 2: The land use change within the UTCW that expected to occur in year 2020 with regular reservoir storage capacity. The database of land use in year 2007 and 2014 was employed to predict land use for year 2020 by applying Markov's Chain model and CA_MARKOV model with IDRISI Taiga model along with creating a land use mapping. The Geographic Information System (GIS) and the SWAT model were finally applied to evaluate the streamflow and water quality (BOD) that could occur in year 2020.

Scenario 3: The simulation consequential effects of regulation water storage from the Krasiao reservoir to dilute waste water caused by downstream land use activities on water quality (BOD) within a sub-watershed in year 2020.

RESULTS

Hydrological response units (HRUs) of the UTCW

The HRUs in the UTCW (Figure 2) corresponding to proportion of land use, soil group and slope of the area was determined by using land use over sub-basin as 5 percent (Figure. 2a), which determine the percentage of soil class over soil group as 10 percent (Figure. 2b) and determine the percentage of slope class over slope class as 10 percent (Figure. 2c). The HRUs in the UTCW were determined at 286 HRUs.

The parameter sensitivity of the streamflow and water quality (BOD)

The sensitivity analysis of SWAT model to indicate uncertainties and appropriate adjustment coefficient of various parameters was performed. The results are described in Table 1 as follows:

Results of calibration of the streamflow and water quality (BOD)

The calibration of SWAT model using the analyzed sensitivity in form of R^2, NSE and MSE starting from calibration of the upper sub-watershed to the sequential lower sub-watersheds. The first calibration parameter is streamflow followed by water quality (BOD), respectively. The seven monitoring stations within the UTCW including station C 51, T12 A, SW 2, TC 27, TC 26, SW4 and SW5 were employed for calibration. The result of calibration accuracy was shown in Table 2 as follows:

The results of the predicted streamflow and water quality (BOD) in the UTCW

Based on the adjusted calibration values and sensitivity analysis in (Table 1), the effects of land use change on the

streamflow and water quality (BOD) including water drainaged from the Krasiao reservoir on dilution of waste water for 3 different scenarios can be described as follows:
Scenario 1: Existing land use condition in the UTCW during 2013 to 2014 (Figure. 3). The result indicated that the total amount of the streamflow from the UTCW was 374.74 MCM with the highest value in September (126.27 MCM) because of cumulative rainfall and soil water content in rainy season and the lowest in March (0.33 MCM) due to dry season (Figure. 3a). The average water quality (BOD) of UTCW was 2.70 mg/L with the highest value in March up to 5.24 mg/L. When the stream has a low water level and the lowest in September, BOD was 0.77 mg/L because the amount of BOD was diluted by high water discharge (Figure. 3b).

The result in this study found that when the ratio of land use change from Scenario 1 to Scenario 2 as shown in Table 3, the total amount of the streamflow of UTCW was 309.02 MCM dropping of 65.72 MCM when compared to Scenario 1. The highest value occurred in September (89.00 MCM) and the lowest in March (0.55 MCM) because the surface water drainage out as groundwater and without rainfall (Figure. 4a). The average water quality (BOD) of UTCW was 2.70 mg/L, in which highest value occurred in January up to 5.31 mg/L and lowest in September at 0.99 mg/L (Figure. 4b).

Krasiao reservoir for diluting waste water caused by land use activities of downstream areas on water quality (BOD) (Figure. 5).

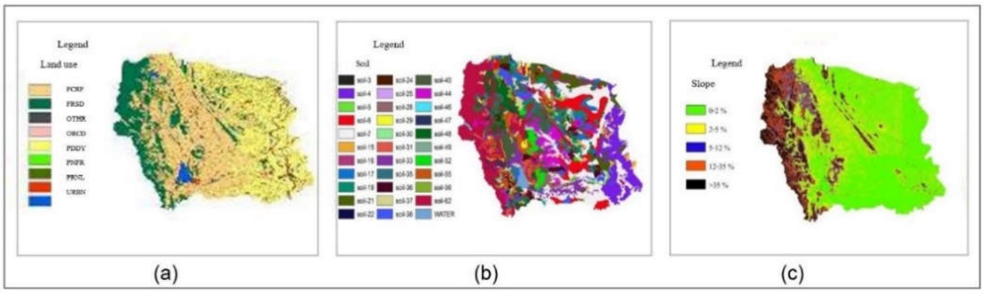


Figure 2. The HRUs of land use (a), soil group (b) and slope class (c) in the UTCW

Table 1. Result of parameter sensitivity analysis for streamflow and water quality (BOD) of UTCW

Main parameters	Parameters in SWAT to be adjusted	Adjusted coefficient of parameters
Streamflow	- Base flow recession constant (ALPHA_BF)	0.22325
	- Available water capacity (SOL_AWC)	0.825
	- Effective hydraulic conductivity of channel (CH_K2)	162.43251
	- Manning's value for tributary channels (CH_N2)	0.05
	- Soil evaporation compensation coefficient (ESCO)	0.025
	- Maximum canopy storage (CANMX)	42.5
	- Potential maximum canopy height (BLAI)	1.45
	- SCS moisture condition 2 curve number for pervious areas (CN2)	83.825
Water quality (BOD)	- Density of biomass (BIO_BD)	925
	- BOD decay rate coefficient (COEFF_BOD_DC)	3.8975
	- Mortality rate coefficient (COEFF_MRT)	0.72775
	- Respiration rate coefficient (COEFF_RSP)	0.13375
	- A conversion factor representing the proportion of mass bacterial growth and mass BOD degraded in the STE (COEFF_BOD_CONV)	0.29

Table 2. The results of calibration accuracy based on R^2, NSE and MSE on streamflow and water quality (BOD) for the UTCW using SWAT model with adjusted coefficient of parameter inTable 1

Parameter	Station code	R^2	NSE	MSE	Period of observed data
Streamflow	C 51	0.83	0.80	7.32	Jan 2013 - Mar 2014
	T12 A	0.85	0.78	13.96	Jan 2013 - Dec 2014
Water quality (BOD)	SW 2	0.72	0.70	-2.88	Nov 2013, Jan 2014, May 2014
	TC 27	0.94	0.85	9.23	Feb, May, Aug, Nov 2013 Mar, Aug 2014
	TC 26	0.91	0.76	14.14	Feb, May, Aug, Nov 2013 Mar, May,Aug,Nov 2014
	SW4	0.49	-1.39	16.89	Nov 2013, Jan 2014, May 2014
	SW5	0.90	0.86	-4.51	Nov 2013, Jan 2014, May 2014

Table 3. The land use change ratio of the UTCW during 2013 to 2014

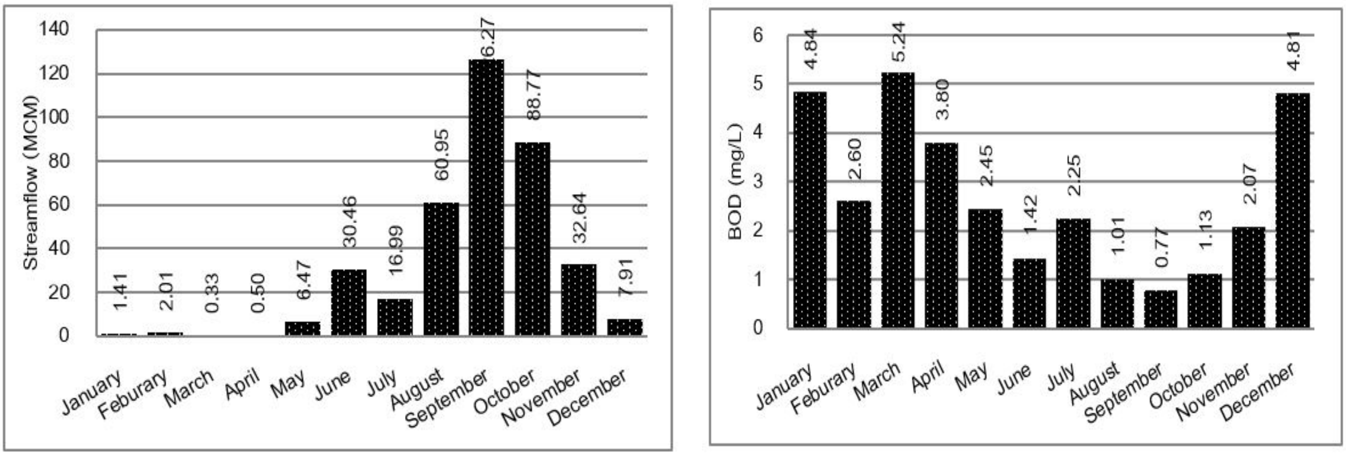
(Scenario 1) and in year 2020 (Scenario 2)

Order	Type of land use	Scenario1		Scenario2		Land use change	
		km^2	%	km^2	%	km^2	%
1	Field crop (FCRP)	2,006.86	38.20	2,087.92	39.74	81.06	1.54
2	Forest area (FRSD)	967.30	18.41	939.93	17.89	-27.37	-0.52
3	Other (OTHR)	91.60	1.74	102.14	1.94	10.54	0.20
4	Orchard(PRCD)	79.85	1.52	68.28	1.30	-11.57	-0.22
5	Paddy field (PDDY)	1,520.91	28.95	1,478.45	28.14	-42.46	-0.81
6	Planted forest (PNFR)	3.85	0.07	3.27	0.06	-0.58	-0.01
7	Perennial land (PRNL)	150.11	2.86	152.50	2.90	2.39	0.04
8	Urban area (URBN)	269.99	5.14	240.95	4.59	-29.04	-0.55
9	Water area (WATR)	163.49	3.11	180.62	3.44	17.13	0.33
Total		5,253.96	100	5,253.96	100	-	-

Table 4. The water quality (BOD) derived at normal and proposed water drainageof the Krasiao reservoir

Period	Normal drainage of the Krasiao reservoir [1*]			Proposeddrainage of the Krasiaoreservoir[2*]		
	Flow rates (CM/sec)	Water volume (MCM)	BOD (mg/L)	Flow rates (CM/sec)	Water volume (MCM)	BOD (mg/L)
January	28.78	2.49	3.24	82.15	7.10	1.50
February	163.21	14.10	1.52	175.00	15.12	1.50
March	321.98	27.82	2.70	386.73	33.41	1.50
April	263.32	22.75	1.38	263.32	22.75	1.38
May	298.96	25.83	1.16	298.96	25.83	1.16
June	169.30	14.63	0.72	169.30	14.63	0.72
July	239.41	20.69	1.25	239.41	20.69	1.25
August	477.27	41.24	1.17	477.27	41.24	1.17
September	240.90	20.81	1.04	240.90	20.81	1.04
October	283.24	24.47	1.05	283.24	24.47	1.05
November	240.85	20.81	1.46	240.85	20.81	1.46
December	41.84	3.61	3.08	216.23	18.68	1.50
Average	230.76	19.94	1.65	256.11	22.13	1.27
Total	-	239.25	-	-	265.54	-

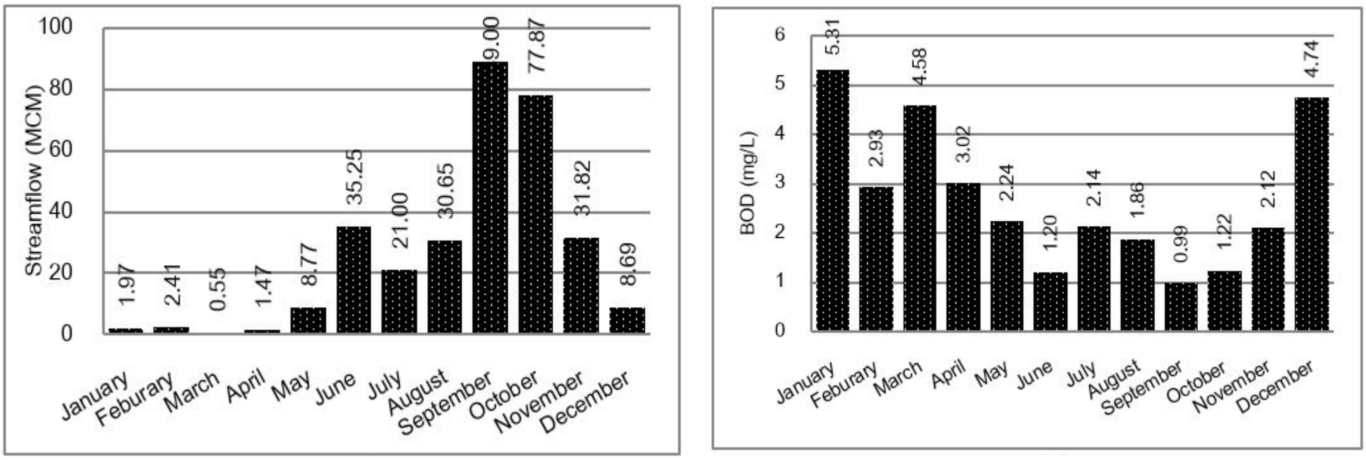
Remark:[1*] Observed values; [2*] Simulated value by SWAT model



(a) **(b)**

Figure 3. The result of the streamflow (a) and water quality (BOD) (b) (Scenario 1)

Scenario 2: Land use condition of the UTCW in the future at year 2020 (Figure. 4).



(a) **(b)**

Figure 4. The result of the streamflow (a) and water quality (BOD) (b) (Scenario 2)

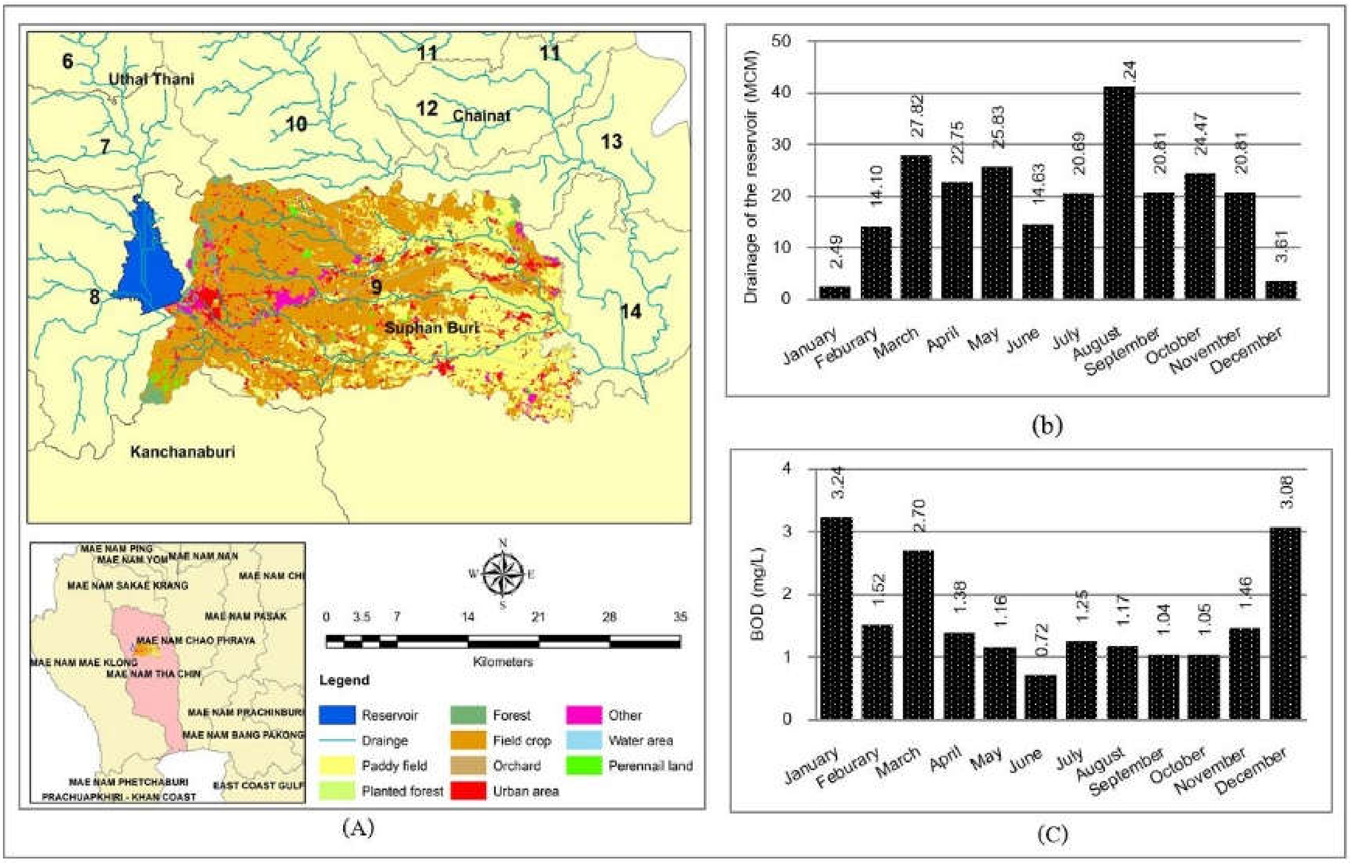


Figure 5. The amount of drainage and BOD of the Krasiao reservoir in sub-watershed No. 9 (Scenario 3)

The investigation for Scenario 3 specified in sub-watershed at 9 and land use in year 2020 (Fig. 5a) with the drainage of the Krasiao reservoir on water quality in form of monthly BOD comparing between normal and proposed dilution of waste water. The water quality (BOD), especially during the higher water quality standard of surface water as class 2 (to conserve aquaculture: BOD < 1.5 mg/L) (Pollution Control Department, 1994). In normal water regulation, the average drain out of the Krasiao reservoir was at 239.25 MCM/year, with the highest drained in August at 41.24 MCM and the lowest in January at 2.49 MCM (Fig. 5b). The water quality (BOD) during 4 months of dry season (from December to March) that higher than the standard surface water quality was estimated by SWAT at 3.08, 3.24, 1.52 and 2.70 mg/L, respectively (Fig. 5c). In order to reduce BOD to meet the standard surface water quality (Class 2 BOD < 1.5 mg/L), the monthly water drained out of the Krasiao reservoir would be increased form 2.49, 14.10, 27.82, and 3.61 MCM to 7.10, 15.12, 33.41, and 18.68 MCM during dry season (from December to March). The result was shown in Table 4.

DISCUSSION

Application of mathematical model for the dilution of waste water from land utilization in the Upper Tha Chin Watershed was the scenario 1 the amount of the streamflow was 374.74 MCM and BOD was 2.70 mg/L. In scenario 2, the amount of the streamflow decreased to 65.09 MCM and BOD was 2.70 mg/L when compared to the scenario 1. In scenario 3 it was found that draining of the reservoir in normal case, BOD during December, January, February and March was 3.08, 3.24, 1.52 and 2.70 mg/L respectively, and a decreased to 1.50 mg/L when an increasing drainage of the Krasiao reservoir from 3.61, 2.49, 14.10 and 27.82 MCM to 18.68, 7.10, 15.12 and 33.41 MCM. The study found that a greater increasing the drainage of the Krasiao reservoir to a higher rate, especially during dry season, the amount of water in the stream regulated from the reservoir can help water quality (BOD) return to class 2 of the standard of surface water quality (BOD < 1.5 mg/L). Therefore this study implied that SWAT model was able to apply for simulating and assessing the effects of land use activities on streamflow, sediment, and water quality (BOD) including draining of the Krasiao reservoir successfully in the watershed and sub-watershed as well.

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