The Effect of Deforestation on Sediment in the Upper River Basin of the Lam Phra Phloeng Reservoir, Thailand

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Abstract
Land use in the upper river basin of the Lam Phra Phloeng reservoir, especially the forested area has mainly been for agricultural and residential purposes. The area suffers periodically from floods and droughts. Increased erosion since forest clearance has led to the increase of sediment load in rivers draining into the reservoir. As a result, sediment deposition in the reservoir gradually decreased the water storage capacity from 150 million m^3 in 1970 to 108 million m^3 in 2014. The objective of this study is to estimate the sediment loaded to the Lam Phra Phloeng reservoir based on the 10% and 25% deforestation using SWAT Model. SWAT is hydrological model which continuously simulate time model and operates on a daily time step at basin scale. The land use map on 2008 and the weather data during January 1981 to March 2010 were computed to simulate the monthly sediment. The results for land use for 10, 20, 50 and 100 year period are provided. If there is 10% deforestation, the accumulated annual sediment at the rainfall return period 10, 20, 50 and 100 year consist of 17.15, 18.33, 21.90 and 31.50 tons/ha, respectively. Also, for the 25% deforest, they are 36.08, 38.12, 45.53 and 65.81 tons/ha at the rainfall return period 10, 20, 50 and 100 year respectively.

Keywords: Deforestation, Erosion, Sediment, SWAT model, Reservoir

Introduction

Erosion is the most important mechanism of land degradation in the study of watershed scale because it adversely affects agricultural productivity through reducing the availability of water, nutrients, and organic matter (Cho and Zoebisch, 2003). The wearing down of a landscape is defined to be one of the erosion process and it is included the detachment, transport, and deposition of soil particles by the erosion forces of raindrops and surface flow of water. Erosion is a matter of concern to watershed and natural resource manager. The main purpose of a reservoirs are water supply and flood control. Erosion upstream of a reservoir deposits sediment in the bottom of the reservoir which lowers the reservoir's water-holding capacity and consequently its usefulness for the both of these purposes.

During 1990-1997, the Southeast Asia has experienced the highest rate of deforestation (0.91% per year) (Lambin et al., 2003). Thailand is a particular case in point (Azam et al., 2008; Singzon, 2006; Biswas, 1999). About 42% of the country was covered with forest in 1973, and the forested area was decreased to 28% by 1988 (Sumarlan, 2004). Then, the Royal Thai Government declared the forest areas closed in 1989 since the forest clearance for agriculture continued, leading to widespread land degradation. However, about one-third of the existing agricultural area was classified as vulnerable to increased soil erosion in 2002 (DEQP and UNEP.RRC.AP, 2006).

The upper area of the Lam Phra Phloeng reservoir is classified to be one of the most active agricultural areas in Thailand (Phetprayoom et al., 2009). During 1974 to 1985, forest area was reduced from 53,100 ha to 16025 ha or about 70% to be agricultural area. The forest area was continuously decreased about 80.35 sq.km from 2002 to 2005 and was converted to agricultural land. Sediment between 2002 and 2005 was found to increase approximately 185,341 tons/year. The result of deforestation has led to the increasing of sediment load in rivers draining into the reservoir. The water storage capacity gradually decreased from 150 million m^3 in 1970 to 121 and 108 million m^3 in 1983 and 2014, respectively (Heijnis et. al, 2003 and Lorsirirat, 2007). It presented that the sediment greatly increased by the land use change. Thus, the study of the upper Lam Phra Phloeng reservoir focuses on one of the most serious sedimentation problems in Thailand.

The objective of this study is to estimate the sediment loaded to the Lam Phra Phloeng reservoir based on the 10% and 25% deforestation using SWAT Model. The data required for SWAT Model can be derived from topographic, soil map, Digital Elevation Model (DEM) and land-use cover classification maps managed by the Land Development Department (LDD). The hydrological data set including evaporation, temperature, humidity, sun radiation, wind speed and rainfall was provided by the Royal Irrigation Department (RID) and Thai Meteorological Department (TMD).

A Description of Study Area

The Lam Phra Phloeng reservoir at 15°30'34" N and 101°50'28"E is located in the Lam Phra Phloeng river basin - part of the Mun river catchment - in the Thai Province of Nakhon Ratchasima shown in Figure 1. The catchment area of the Lam Phra Phloeng river basin is 231,000 ha while the upper river basin of the reservoir is

77,100 sq.km or 33.38%. The annual inflow to reservoir is about 169.75 million m^3/year over the period from 1981 to 2010. The general topography is undulating with many small hills. The elevation varies between 260-1,150 m above mean sea level. The soil texture is predominantly silly loam with gently undulating loam soil.

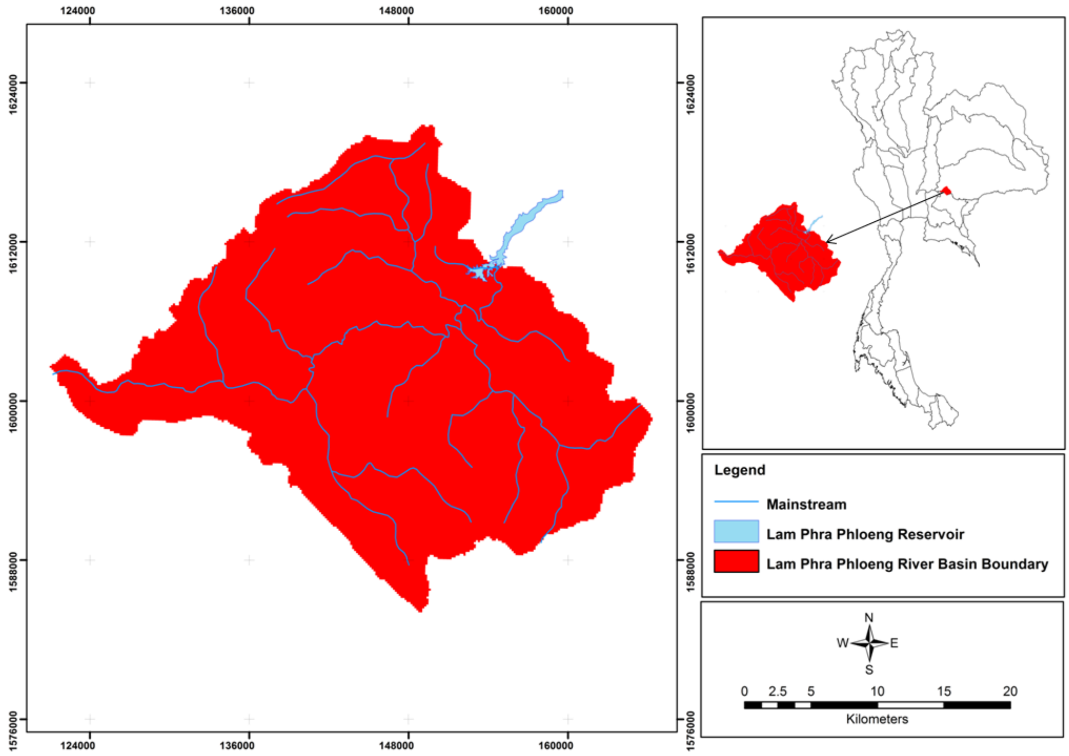

Figure 1: The upper Lam Phra Phloeng reservoir

The climate of the study area is typically tropical savannah affected by monsoon. The rainy season is from May to October while the dry season runs from November to April. The annual rainfall is about 1,135.80 mm/year and ranged from 714.10 to 1,567.60 mm/year for the period 1981 to 2010. Since the study area is in a tropical climatic zone, there are three temperature regimes: cool dry, hot dry, and the rainy season. The cool dry is from mid-October to mid-February and the lowest temperature is in December (23°C). On the other hand, the hot dry runs from mid-February to mid-May and the highest normal daily temperature is 29.7°C (Shahriar et al., 2008).

The initial cropping system was subsistence oriented and mainly based on indigenous knowledge that continued only for a couple of years. Currently, the cropping pattern changed from subsistence to market-oriented farming (Cho and Zoebisch, 2003). In 2008, land use in the upper Lam Phra Phloeng reservoir was dominated for agriculture land (60.78%), forest (34.44%), urban area (3.31%) and water resources (1.47%). Agricultural land is mainly consisted of rice field, maize, sugarcane, cassava and vegetables. The forest is included by tropical rain forest, deciduous forest and wood lot.

Methodology

To determine monthly sediment, daily weather data during 1981 to 2010, digital elevation model (DEM), land use 2008 and soil map were mainly input data for SWAT model. The research methodology is presented in Figure 2.

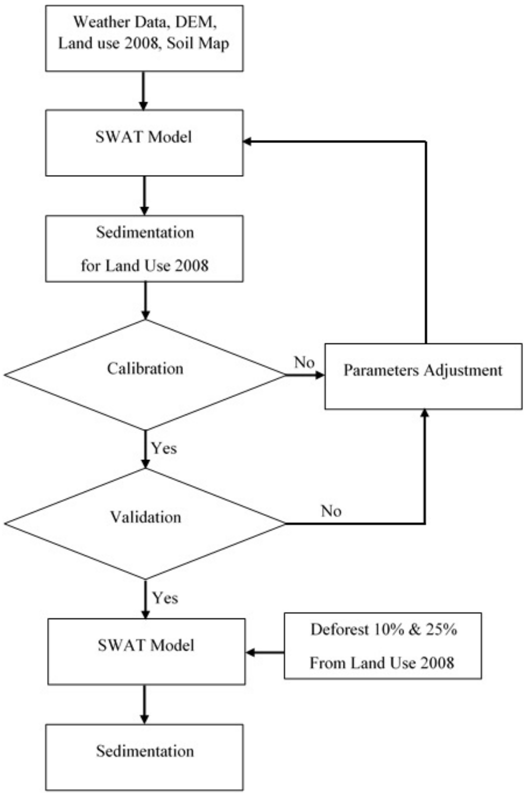

Figure 2: The research methodology for sediment estimation

Soil and Water Assessment Tool (SWAT)

To understand the hydrological cycle change and associated potential of sediment, this study applied SWAT model to evaluate the sediment in the upper Lam Phra Phloeng reservoir. SWAT is hydrological model which continuously simulate time model and operates on a daily time step at basin scale. In watershed scale, all of a range in climatic, soils, topographic, and land use condition are input data. Normally, SWAT is applied to determine hydrology element, sedimentation, nutrients, pesticides, agricultural management, and stream routing (Arnold et al., 1998). However, this study focuses only on a hydrology element that is sedimentation.

Since the study area is included the large scale spatial heterogeneity, considering information from the digital elevation model (DEM), the soil and land use map is divided into sub-basins and each sub-basin is discriminated into a series of hydrologic response units or HRUs, which are unique soil and land use. Moreover, each sub-basin is consisted of slope, reach dimensions, and climate data. For climate data, the station nearest to the centroid of each sub-basin is considered. The routing through the river system is concerned using the variable storage or Muskingum method (Abbaspour et al., 2007). Since the weather station network in the study area is not very dense and data duration is quite short, to simulate missing data, the weather generator program WXGEN is applied in SWAT model. The WXGEN program fills data gap or extends time series of daily data based on monthly statistics (Schuol et al., 2008).

To compute sediment, the surface runoff is firstly computed using the concept of water balance and the sediment is then estimated using the concept of the Modified Universal Soil Loss Equation (MUSLE) (William, 1975). The concept of water balance is concerned using the elements of hydrology cycle shown in equation (1) and (2). To accurately calculate water balance, there are two major divisions of hydrologic cycle for the watershed. Firstly, the land phase of the hydrologic cycle is analyzed to control the amount of water loading to the main channel in each sub-watershed. Secondary, the water phase of the hydrologic cycle is calculated for the movement of water through the channel network of the watershed to the outlet.

$$S_f = S_i + \sum_{i=1}^{t} (P - Q_s - ET - w - Q_g) \tag{1}$$

where S_f is the final soil water content (mm H_2O), S_i is the initial soil water content (mm H_2O), t is the time (days), P is the precipitation on day i (mm H_2O), Q_s is the surface runoff on day i (mm H_2O), ET is evapotranspiration on day i (mm H_2O), w is the water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_g is the return flow on day i (mm H_2O).

$$Q_s = \frac{(P - I_a)^2}{(P - I_a + S)} \tag{2}$$

where I_a is the initial abstractions included surface storage, interception and infiltration prior to runoff (mm H_2O), and S is the retention parameter (mm H_2O) that depends on the change of soil, land use, management and slope.

The Modified Universal Soil Loss Equation (MUSLE) is applied to compute erosion caused by rainfall and runoff (William, 1975). MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1960, 1978). The average annual gross erosion as a function of rainfall energy is predicted USLE. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, eliminated the need for delivery ratios, and allows the equation to be applied to individual storm events.

The sediment is computed by using the Modified Universal Soil Loss Equation (MUSLE) (William, 1995) shown in equation (3):

$$Sed = 11.8(Q_{surf}*q_{peak}*area_{hru})^{0.56}*K_{USLE}*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG \tag{3}$$

where *sed* is the sediment yield on a given day (metric tons), Q_{surf} is the surface runoff volume (mm H_2O/ha), q_{peak} is the peak runoff rate (m /s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the Universal Soil Loss Equation (USLE) soil erodibility factor (0.013 metric ton m^2hr/(m^3-metric ton cm)), C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor.

The modified version of the rational equation is applied to compute the peak runoff rate shown in equation (4).

$$q_{peak} = \frac{C \cdot i \cdot A}{3.6} \qquad (4)$$

where q_{peak} is the peak runoff rate ($m^3.s^{-1}$), i is the rainfall intensity ($mm.h^{-1}$), A is the subbasin area (km^2), and 3.6 is a unit conversion factor.

The soil erodibility factor is defined as the soil loss rate per erosion index unit for a specified soil as measured on a unit plot. A unit plot is 22.2-m (72.6-ft) long, with a uniform length-wise slope 9%, in continuous fallow, tilled up and down the slope. Direct measurement of the erodibility factor is time consuming and costly (Wischmeier and Smith, 1978). Moreover, a general equation to calculate the soil erodibility factor, when the silt and very fine sand content makes up less than 70% of the soil particle size distribution, is developed by Wischmeier et al. (1971) presented in equation (5):

$$K_{USLE} = [0.00021*M1.14*(12-OM) + 3.25*(c_{soilstr}-2) + 2.5*(c_{perm}-3)]/100 \qquad (5)$$

where M is the particle size parameter, OM is the percent organic matter (%),$c_{soilstr}$ is the soil structure code used in soil classification, and c_{perm} is the profile permeability class.

The USLE cover and management factor or C_{USLE} is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled (Wischmeier and Smith, 1978). Since plant cover varies during the growth cycle of the plant, SWAT updates C_{USLE} daily using the equation (6):

$$C_{USLE} = \exp ([\ln(0.8) – \ln(C_{USLE,\,mm})]*\exp [-0.00115*rsd_{surf}] + \ln[C_{USLE,\,mm}] \qquad (6)$$

The support practice factor or P_{USLE} is the ratio of soil loss with a specific support practice to the corresponding loss with up-and –down slope culture. Wischmeier and Smith (1978) define the P factor values and slope-length limits for contouring as Table 1.

Table 1 P factor values and slope-length limits for contouring

Land slope (%)	P_{USLE}	Maximum length (m)
1 to 2	0.60	122
3 to 5	0.50	91
6 to 8	0.50	61
9 to 12	0.60	37
13 to 16	0.70	24
17 to 20	0.80	18
21 to 25	0.90	15

The topography factor or LS_{USLE} is defined as the expected ratio of soil loss per unit area from a field slope to that from a 22.1 m length of uniform 9% slope under otherwise identical conditions. The topographic factor is calculated by equation (7):

$$LS_{USLE} = (L_{hill}/22.1)^m*(65.41* \sin^2(\alpha_{hill}) + 4.56*\sin \alpha_{hill} + 0.065) \quad (7)$$

where L_{hill} is the slope length (m), m is the exponential term, and α_{hill} is the angle of the slope.

The coarse fragment factor, CFRG, is calculated by equation (8):

$$CFRG = \exp(-0.053*rock) \quad (8)$$

where *rock* is the percent rock in the first soil layer (%).

SWAT Model Sensitivity Analysis

Sensitivity analysis was conducted to concern the influence of parameters that had on estimating sediment. Parameters were analyzed for the sensitivity analysis of calibration and validation parameters shown in Table 2.

Table 2 The calibration and validation parameters for sensitivity analysis

Parameter	Value
Spcon: Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing	0.001
Spexp: Exponent parameter for calculating sediment reentrained in channel sediment routing	1.2
Usle_P: USLE equation support practice	0.18

Calibration and Validation

The calibration and validation focused on the periods of January 2003 – December 2006 and January 2007 – March 2010, respectively. Calibration and validation were completed by comparing time series model results to gaged monthly sediment at station M171 located in the upper reservoir. Two criteria for the goodness of fit – the graphical comparison and the Nash-Sutcliffe efficiency (NSE) coefficient – were used for calibration and validation. Graphical comparison is extremely useful for judging the results of model calibration and model validation. It is overlooked by coefficient of determination (R^2). The graphical comparisons of calibration and validation are presented in Figure 3 (R^2 = 0.93) and Figure 4 (R^2 = 0.97), respectively. In addition, the Nash-Sutcliffe efficiency (NSE) coefficient is an indicator of a model ability to predict about the 1:1 line. The NSE coefficients for calibration and validation are 0.87 and 0.90, respectively. The closer the value is to 1.0, the more accurate the model.

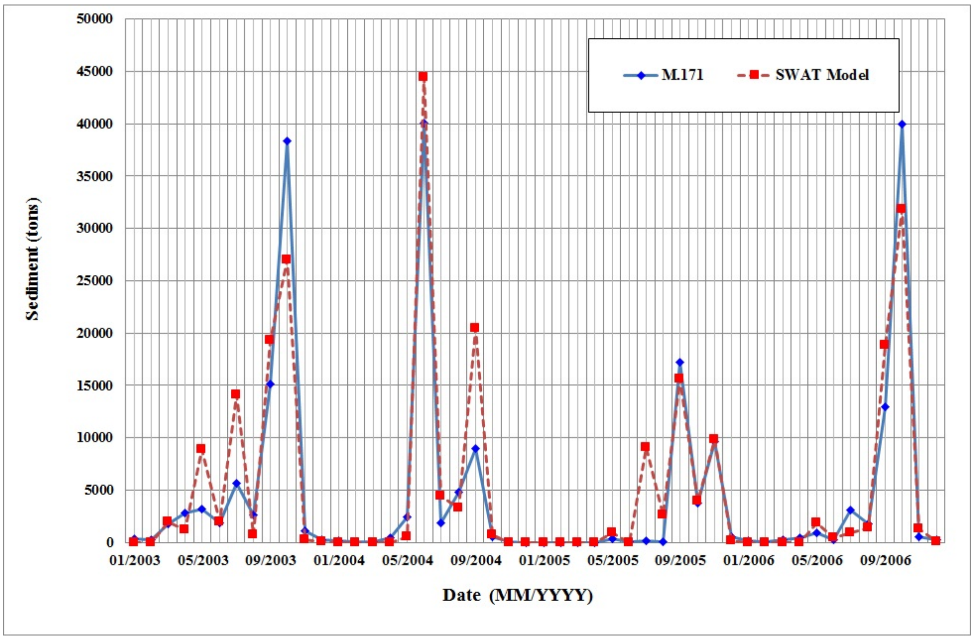

Figure 3: The comparison of mean monthly sediment between SWAT model and recorded data at M171 station during January 2003 – December 2006

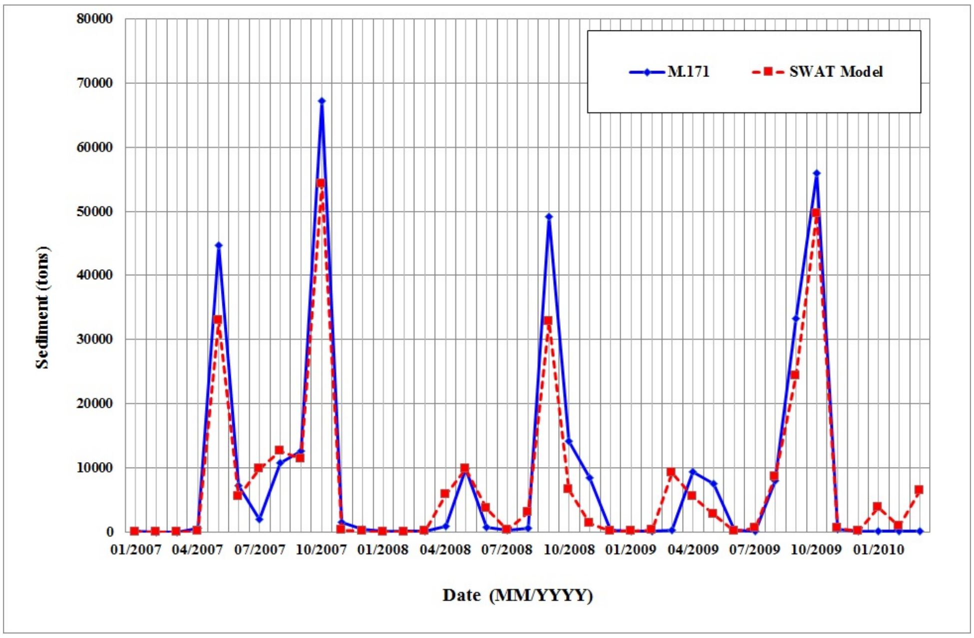

Figure 4: The comparison of mean monthly sediment between SWAT model and recorded data at M171 station during January 2007 – March 2010

After SWAT model was calibrated and validated based on land use 2008, this model was analyzed to predict monthly sedimentation for 10% and 25% deforestation. The forest area was transformed to agricultural area as the past. For 10% deforestation, forest area and agricultural area were 28.36% and 66.86%, respectively. On the other hand, for 25% deforestation, forest area and agricultural area were comprised by 19.25% and 75.96%, respectively. However, urban area and water resources were not changed for this study.

Results and Discussion

The upper Lam Phra Phloeng reservoir was classified to 17 sub-basin and 248 HRUs based on DEM, land use, soil type and slope. The sediments for rainfall return period 10, 20, 50, and 100 year are presented in Table 3. They can be explained that, in land use 2008, the accumulated annual sediment occurred in the upper reservoir for return period 10, 20, 50, and 100 year are 14.68, 15.68, 18.96, and 27.40 tons/ha, respectively. Moreover, the accumulated annual sediment drained to the reservoir for return period 10, 20, 50, and 100 year are 784900, 858500, 1080000, and 1607000 tons, respectively.

In the case of 10% deforestation, the accumulated annual sediment in the upper reservoir for return period 10, 20, 50, and 100 year are included 17.15, 18.33, 21.90, and 31.50 tons/ha, respectively. They increases about 14%-17% from the accumulated annual sediment in land use 2008. The accumulated annual sediment flow to the reservoir for return period 10, 20, 50, and 100 year are contained 916000, 1001000, 1246000, and 1846000 tons, respectively and they also accrue about 14%-17% from that in 2008.

For 25% deforestation, the accumulated annual sediment in the upper basin for return period 10, 20, 50, and 100 year are 36.08, 38.12, 45.53, and 65.81 tons/ha, respectively and they are more than that in land use 2008 about 140% - 146%. The accumulated annual sediment loaded to the reservoir for return period 10, 20, 50, and 100 year are 1767000, 1941000, 242000, and 3648000 tons, respectively. They increases about 125% - 127% from that in 2008.

Furthermore, the results present that if monthly rainfall is less than 100 mm, sediment is insignificantly affected by rainfall. On the other hand, the high sedimentation loaded to reservoir occurs during rainy season and it is due to the inflow from the tributary as well as eroded materials that come from the upland area to the reservoir.

Conclusion

The forest conservation in the upper basin of reservoir should be importantly concerned since raindrop impact can detach soil particles on unprotected land surfaces between rills and initiate transport of these particles to the rills. From the small rills, the particles move to larger rills, into ephemeral channels and then into continuously flowing rivers and reservoir. Entrainment and deposition of particles can occur at any point along the path. Thereafter, the settlement of sediment in the reservoir will bring about a rapid reduction of the ability to storage the maximum quantity of water. The results of this study are a help to policy makers, managers and planners for the appropriate land use planning, management and conservation practices in the study area for reducing the soil erosion.

Additionally, the concerns about water resources management, specifically catchment scale decision making, can be addressed with information on the hydrological processes of sediment generation. Such a case study of sedimentation, represented by simulation data, can be applied to the water resources planning and development.

Return Period	Month	Rainfall (mm)	Mean Sediment (t/ha)			Sediment loaded to reservoir (ton)		
			Land use 2008	Deforest 10%	Deforest 25%	Land use 2008	Deforest 10%	Deforest 25%
10	1	1.41	0.00	0.00	0.00	0.33	0.35	0.43
	2	9.93	0.00	0.00	0.00	0.01	0.02	0.03
	3	52.51	0.02	0.03	0.06	957.70	1,133.00	2,588.00
	4	140.28	0.77	0.94	1.97	31,450.00	38,440.00	66,510.00
	5	213.07	2.46	2.90	5.88	121,100.00	143,200.00	259,700.00
	6	134.89	1.25	1.42	3.03	66,840.00	76,140.00	149,200.00
	7	104.93	1.64	1.83	4.01	98,160.00	109,600.00	227,600.00
	8	178.60	4.54	5.37	11.46	246,400.00	290,900.00	572,500.00
	9	100.59	0.87	1.06	2.16	41,470.00	50,280.00	88,970.00
	10	196.88	3.12	3.61	7.51	178,000.00	205,900.00	399,700.00
	11	14.35	0.00	0.00	0.00	414.00	422.00	424.50
	12	0.00	0.00	0.00	0.00	46.27	45.95	43.56
	Total	1147.45	14.68	17.15	36.08	784,900.00	916,000.00	1,767,000.00
20	1	5.08	0.00	0.00	0.00	0.33	0.34	0.34
	2	8.05	0.00	0.00	0.00	0.15	0.15	0.14
	3	58.23	0.01	0.01	0.02	248.20	281.50	712.00
	4	183.99	2.19	2.64	5.47	110,600.00	131,700.00	252,900.00
	5	143.83	2.38	2.77	5.74	126,200.00	147,200.00	280,000.00
	6	93.38	0.94	1.09	2.40	48,120.00	55,440.00	111,300.00
	7	29.56	0.03	0.04	0.06	1,405.00	1,895.00	3,001.00
	8	128.56	0.66	0.73	1.56	36,850.00	41,470.00	85,190.00
	9	353.21	7.78	9.04	18.86	442,500.00	513,800.00	1,013,000.00
	10	168.11	1.37	1.61	3.24	75,130.00	87,920.00	160,400.00
	11	35.28	0.33	0.40	0.77	17,200.00	20,760.00	33,710.00
	12	3.06	0.00	0.00	0.00	234.10	235.40	238.40
	Total	1210.34	15.68	18.33	38.12	858,500.00	1,001,000.00	1,941,000.00
50	1	3.54	0.00	0.00	0.00	3.61	4.08	5.01
	2	5.10	0.00	0.00	0.00	0.00	0.01	0.01
	3	32.35	0.01	0.01	0.02	110.30	138.10	276.90
	4	157.61	0.40	0.47	0.96	17,070.00	20,460.00	36,060.00
	5	265.44	5.60	6.46	13.41	327,400.00	376,800.00	749,400.00
	6	140.86	1.57	1.74	3.80	92,820.00	102,500.00	211,800.00
	7	59.59	0.68	0.79	1.55	40,650.00	47,880.00	89,520.00
	8	157.36	2.32	2.66	5.63	130,600.00	149,500.00	299,100.00
	9	201.17	2.92	3.34	7.03	168,700.00	193,300.00	379,500.00
	10	286.43	5.16	6.07	12.49	286,500.00	336,500.00	647,300.00
	11	52.01	0.30	0.36	0.66	15,370.00	18,840.00	29,090.00
	12	0.73	0.00	0.00	0.00	250.30	261.10	286.10
	Total	1362.2	18.96	21.90	45.53	1,080,000.00	1,246,000.00	2,442,000.00
100	1	0.00	0.00	0.00	0.00	0.25	0.33	0.48
	2	39.81	0.05	0.06	0.14	1,837.00	2,230.00	4,301.00
	3	14.34	0.00	0.00	0.00	3.29	5.99	6.28
	4	170.68	1.58	1.75	3.72	94,010.00	104,800.00	214,800.00
	5	231.03	6.32	7.10	15.23	390,200.00	438,900.00	912,800.00

	6	160.01	2.98	3.47	7.43	159,600.00	185,900.00	363,000.00
	7	100.2	0.98	1.10	2.31	59,030.00	66,570.00	133,500.00
	8	170.63	3.18	3.66	7.88	175,500.00	201,800.00	407,600.00
	9	375.07	7.30	8.42	17.30	435,400.00	502,200.00	976,300.00
	10	178.09	3.02	3.66	7.03	174,500.00	209,800.00	377,700.00
	11	118.52	1.99	2.28	4.77	116,400.00	133,000.00	257,600.00
	12	0.00	0.00	0.00	0.00	315.60	314.80	299.00
	Total	1558.39	27.40	31.50	65.81	1,607,000.00	1,846,000.00	3,648,000.00

Table 3 Mean sediment and sediment flow to reservoir for return period 10, 20, 50, and 100 year

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