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Prediction Models of the Effect of Basin Characteristics and Forest Cover on Reservoir Sedimentation in Northeastern Thailand

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ABSTRACT

Regression models for predicting the effect of basin characteristics and forest cover on reservoir sedimentation (RS) were formulated using 11 parameters, i.e., basin annual rainfall (Ra), annual inflow (Q), areal distribution of watershed classes (WSC1-WSC5), surface area of water in resservoir (WSA; % of basin area), basin relief ratio (Sr), channel sinuosity (Si) and remaining forest cover (For; %) from 11 basins in northeastern Thailand observed during 1953 to 1986. Bottom survey data from 11 reservoirs in this area are employed to find acceptable correlation between the recorded annual depositions and the mentioned parameters. The derived mathematical statistical equation is:

$$RS = e^{[-7.2348 + 2.5386 \ln Q - 0.0041 For + K]}$$

where $K = (4.442Sr - 2.4077Si - 0.307WSA - 0.524WSC1)$.

It could be postulated basing on the equation that for every 10 percent of decreasing forest area in the basin, about 4-5 percent of reservoir sedimenttation could be annually increased.

Key words : reservoir sedimentation, prediction model, forest conversion, basin characteristics, northeastern Thailand

INTRODUCTION

One of main problems in water resource development project is the reservoir sedimentation which reduces the useful capacity of reservoirs. The water resource development planning can not be successful unless the sediment deposition can be prevented and controlled, These planning will be reliable only if the factors generating sediment transportation and deposition are known or how the annual volume relates to the sediment volume in the reservoir.

Most of the sediment deposition in the reservoirs is generated by surface erosion on the upstreams of reservoir. It's amount and transport depend on onsite erosion which is the consequence of rainfall energy and land use changes, drainage geomorphology, inflow, overland and stream slopes, basin area and type of soil. There were no thorough studies made on reservoir sedimentation in Thailand so far. There are only few offices that are responsible for water resources development projects. Most of study reports were predicting the lifespan of the reservoir based on historical data with paying less attention on impact of land-use changes. The reports concentrate on the methods for the resurvey to construct the contour map of reservoir in order to determine its remaining capacity. This method however can not be applied to forecast the volume of sediment deposition in other reservoirs and it costs more to carry on. Also there is no management implication to reduce or mitigate reservoir sedimentation by means of watershed management.

Prediction of reservoir sedimentation using drainage morphology and land use changes is rarely found in literatures of this region especially in Thailand. In the United States, the relation of sediment deposition to catchment, streamflow, and land-use variables was studied by Anderson (1976) using this

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general model:

Reservoir deposition = f (topography, geology, roads, forest fires, streamflow, precipitation,soil, landslides, and geologic faults)

Based on deposition measurements in 48 northern California reservoirs and the statistical techniques called reduced rank principal component, the reservoir sedimentation was found related to precipitation amount, rain-snow frequency, road standards and location, forest fires, geology, and physiography, and also to differences among watersheds in landslide classes, extent of geologic faults, clay content of watershed soils, and density of reservoir sedimentation.

Study by AIT (1983) indicated that sediment deposited in the resesrvoir in Northeastern Thailand is caused by soil erosion in the basin which is mostly dependent on amount of rainfall, drainage area, soil characteristics, overland slope and vegetative cover. By regression analysis AIT developed prediction model for reservoir sedimentation in the Northeast based on sediment measurement in 8 reservoirs as follows:

$$S = K(AxR)^N$$
$$= 4.5\,(10)^{-3}\,(AxR)^{0.945}$$

where

S = average annual reservoir sediment deposition (million cubic meter)
A = basin area (sq.km)
R = average annual rainfall (mm)
K and N are constant parameters

In China, Lixian *et. al* (undated) employed 10 parameters of drainage morphology and forest cover of 200 check dams to correlated with reservoir sedimentation by multiple regression analysis. Stepwise analysis produced the following prediction model:

$$\ln Y = -2.65103 + 0.96185S + 0.00218L^2 + 8.4129L^{0.5} - 4.16176L^{2/3} + 2.21596B^{0.5} - 1.4913B^{2/3} - 2.22697T + 2.45561T^2 - 1.36285F^2$$

with R^2 = 0.625;F–ratio = 25.15 at 95% confident interval

where

Y = arerage reservoir sedimentation (ton)
S = soil type
L = average basin length (meter)
B = average width of basin (meter)
T = proportion of terrace area in the basin (dimensionless)
F = proportion of forest area in the basin (dimensionless)

There are recently more problems concerning sediment deposition in the reservoir in northeastern Thailand compared to others. Besides the unfavorable soil fertility of sandy soil, the forest cover in the basin has been rapidly converted into cropping area which caused more siltation. The study on the effect of basin morphology and forest conversion on reservoir sedimentation is thus great interest to decision makers. It is especially important to understand the process of reservoir sedimentation and the results can also be applied for planning the development of both the watershed and water resources.

The main objectives of this study are (1) to investigate the effect of drainage morphological factors and forest conversion on ressrvoir sedimentation and (2) to find out the equations to predict sediment volume to be deposited in the planned or unmeasured reservoirs and its management implication in watershed area to reduce reservoir siltation.

MATERIALS AND METHODS

This study establishes a relationship between reservoir sedimentation and drainage morphology and percentage of remaining forest area by regression analysis using 11 reservoirs (Table 1) in the northeastern Thailand as study area.

The increase of sediment volumes in reservoirs (RS) was observed by Royal Irrigation Department (RID). The reservoirs were surveyed within the given time period by range line method levelling from bench marks to the cross-section line and echosounding the bed from the water level in order to establish the contour map of reservoir. Knowing the original volume and know the capacity of reservoir, the sediment volume decreasing the capacity can be determined by comparing the survey results with the base map, and averaged by the given time period of the survey.

Drainage morphometry,i.e., drainage area (DA) sinuosity or stream length ratio (Si) , relief ratio (Sr), compactness coefficient (Kc) and water surface area

(WSA) were measured from topographic map 1: 50,000. Percentage of areal watershed classes (WSC1 to WSC5) (Tangtham and Chunkao, 1990), obtained from watershed classification map, (1:250,000) and the remaining forest area (For.) in the basin of each reservoir were derived from forest map interpreted from LANSAT taken in 1947, 1979 and 1985 by Royal Forest Department (RFD).

Annual inflow (Q) and rainfall (Ra) data and reservoir capacity (Rc) were obtained from the Hydrology Division of RID. Imformation of all parameters are presented in Table 2.

Both stepwise and full model regression analysis were employed to obtain the prediction models.

RESULTS AND DISCUSSION

1) The Effect of Geomorphological Factors

By using the multiple regression analysis to determine the relationship between RS and geomorphological factors in form of correlation matrix, there is no varable in this case to correlate with the RS to 50 percent. Besides, the stepwise analysis showed no variable meet criteria of statistical acceptance. It shows that the parameters are not significant for sedimentation rate in form of simple linear regression.

Using scatter plotting between RS and the parameters, it was found that nonlinear regression equation between RS and Inflow (Q) is more fitted and other paramerers take the form of a linear regression line. By stepwise analysis, only 3 parameters were selected, i.e., inflow volume (Q), drainage area (DA) and relief ratio (Sr). The equation to predict the increased sediment volume is:

$$\ln RS = -11.1354 + 2.8515 \ln Q - 0.0045 DA - 0.7229 Sr;\ R^2 = 0.8207;\ \text{and F-ratio} = 16.78 \quad ...(1)$$

Where the unit of RS is million cubic meter per year, Q is million cubic meters, DA is sq.km and Sr is m/m. These three predictors corespond to a statestical confidence interval of 95 percent.

When the equation was determined using the full model form, the R^2 is increased to 0.9336 and the F-ratio reduced to 7.806 a little higher than F-table 4.71 . The derived equation is:

$$\ln RS = 2.1028 + 1.5598 \ln Q + 0.0054 Ra - 0.0291 For + 0.0072 DA - 8.3696 Si + 0.689 Sr - 6.2545 Kc - 0.0203 WSA - 0.0084 Rc;\ R^2 = 0.9336;\ \text{and F-ratio} = 7.806 \quad ....(2)$$

The nine parameters are responsible to the acceptable R^2 and they correspond to a statistical confidence interval 95 percent.

When the drainage area is disintegrated into 5 different zones by combining the slope steepness with the landform, elevation, soil and geologic formation

Table 1 Location of reservoirs and periods of sedimentation survey used in the investigation.

Reservoir No.	Name of Reservoir	Location: District	Location: Province	Approximated Lat.N Long.E	Survey No.	Sedimentation period
1/1	Huay Kor	Na Chuak	Maha Sarakham	16°05' 103°05'	1	1967-4978
1/2	Huay Kor	Na Chuak	Maha Sarakham		2	1979-1983
2/1	Huay Sab-pradu	Sikhiu	Nakhon Ratchasima	14°45' 101°42'	1	1975-1979
2/2	Huay Sab-pradu	Sikhiu	Nakhon Ratchasima		2	1980-1984
3/1	Huay Ang	Muang	Roi-Et	16°05' 103°30'	1	1964-1977
3/2	Huay Ang	Muang	Roi-Et		2	1978-1982
4/1	Huay Kaeng	Muang	Kalasin	16°32' 103°45'	1	1967-1980
4/2	Huay Kaeng	Muang	Kalasin		2	1981-1986
5	Lam Takhong	Sikhiu	Nakhon Ratchasima	15°50' 101°35'	1	1979-1984
6	Lam Phra Phloeng	Pak Thong Chai	Nakhon Ratchasima	14°32' 101°05'	1	1967-1983
7	Sirindhorn	Phibun Mungsahan	Ubon Ratchathani	15°12' 105°30'	1	1972-1982
8	Huay Khilek	Nikhom Kham Sroi	Mukdahan	16°25' 104°45'	1	1965-1981
9	Huay Jorakemak	Muang	Buri Ram	14°55' 103°10'	1	1956-1980
10	Huay Kud-daeng	Chaturaphak Phiman	Roi Et	15°45' 103°25'	1	1953-1980
11	Huay Yang	Pak Thong Chai	Nakhon Ratchasima	14°38' 102°05'	1	1957-1980

Table 2 **Annual increased sediment deposition, drainage morphology, reservoir characteristics and related hydrological parameters of studied reservoirs in Northeastern Thailand.**

Reservoir No.	Reservoir Sedimentation (MCM/yr) RS	Annual Inflow (MCM) Q	Annual Rainfall (MM) Ra	Forest Cover (%) For	Storage Capacity (MCM) Rc	Slope of Reservoir (m/m) Rs	Basin Area (sq,km) DA	Stream Length Ratio (l/L) Si	Relief Ratio Sr	Watershed Class area					Reservoir water surface (%) of DA (WSA)
										1 (%)WSC1	2 (%)WSC2	3 (%)WSC3	4 (%)WSC4	5 (%)WSC5	
1/1	0.0790	40.0140	1332.0	15.6200	31.0545	0.2642	232.2000	1.1850	0.0200	0.0000	0.0000	0.0000	40.5900	57.8000	1.6100
1/2	0.9440	76.2080	1251.7	0.0010	26.8480	0.2172	232.2000	1.1850	0.0200	0.0000	0.0000	0.0000	40.5900	57.8000	1.6100
2/1	0.0426	64.1730	1063.2	32.1900	27.3439	0.3174	170.0000	1.2940	3.1200	28.8500	2.6300	26.1100	24.7200	13.8900	4.1300
2/2	0.0993	65.7580	950.3	024.9700	26.9289	0.3221	170.0000	1.2940	3.1200	28.8500	2.6300	26.1100	24.7200	13.8900	4.1300
3/1	0.0986	28.9000	1375.0	7.9700	19.2569	0.2750	144.0000	1.2220	0.1600	0.0000	0.0000	0.0000	23.4400	72.4000	4.1700
3/2	0.2515	46.1100	1397.7	0.0010	18.6260	0.2460	144.0000	1.2220	0.1600	0.0000	0.0000	0.0000	23.4400	72.4000	4.1700
4/1	0.6315	46.4400	1381.0	28.5000	35.6823	0.3489	149.0000	1.1340	0.3400	0.0000	0.0000	0.0000	34.0600	63.2600	2.6800
4/2	0.8483	37.8400	1341.5	0.0010	25.4507	0.2735	149.0000	1.1340	0.3400	0.0000	0.0000	0.0000	34.0600	63.2600	2.6800
5	0.3570	390.2200	1021.0	16.1900	234.8400	0.2530	1430.0000	2.2730	1.8100	18.5800	3.0400	7.5500	8.6000	61.4000	1.3600
6	1.8253	252.2040	1250.0	58.1900	135.9880	0.3179	820.0000	1.4330	1.4300	17.2900	6.8900	29.9700	32.0400	13.2900	0.5200
7	0.2256	1043.9200	1720.0	54.1300	1967.1280	0.1670	2097.0000	1.4120	0.1700	7.1100	9.8700	2.7600	27.4200	40.0600	12.7800
8	0.1956	37.6400	1524.6	52.5500	25.4148	0.4592	78.6000	1.0260	0.6600	5.2000	7.3000	24.5000	29.5000	30.3000	3.2000
9	0.0246	23.4860	1209.5	0.0010	21.1829	0.2075	113.6000	1.1450	0.1300	0.0000	0.0000	0.0000	0.0000	94.7200	5.2800
10	0.0030	7.7980	1332.4	0.0010	2.7675	0.4000	45.0000	1.1370	0.1500	0.0000	0.0000	0.0000	0.0000	97.2200	2.7800
11	0.0147	10.1810	1070.0	0.0010	5.3691	0.3640	42.0000	1.1250	0.3700	0.0000	0.0000	0.0000	30.0000	65.4800	4.5200

(which is called watershed class, WSC1 to WSC5) and applied to derive prediction model by stepwise regression analysis. The equation to predict the RS is:

$$\ln SR = -6.671 + 2.5938 \ln Q - 0.5421 WSC1 - 0.3782 WSA + 4.7585 Sr - 3.412 Si \quad ....(3)$$

with correlation coefficient $R^2 = 0.9421$ and all paramerers correspond to a statistical confedence interval 99 percent.

Equation (3) indicates that watershed class 1 (WSC1), water surface area in the reservoir (WSA) as well as channel sinuosity (Si) play significant role on reducing reservoir sedimentation. Although, WSC1 is generally characterized as steep slope with dissected landform and easily erodible soil on high elevation, it was mainly covered by dense forest during the period of data collection. The larger the amount ot annual discharge (Q) and the steeper the basin relief (Sr), is certainly resulted in the greater the amount of reservoir sedimentation. Equation (3) also implies that WSC1 with good forest cover can maintain smaller rate of reservoir sediment deposition.

2) The Combined Effect of Forest Conversion

In order to determine the effect of conventional land-use changes by converting forest into agricultural crops in the northeastern region on the increased reservoir-sedimentation, the remaining forest area (For,%) was added to derive prediction model for the watershed management purpose. The equation is:

$$\ln RS = -7.2348 + 2.5386 \ln Q - 0.524 WSC1 - 0.307 WSA + 4.4442 Sr - 2.4077 Si - 0.0041 For, \quad ......(4)$$

with $R^2 = 0.872$ and F-ratio = 9.168

Although parameter (For) shows insignificant effect on RS from the statistical point of view, it implies management techniques in reducing RS by means of forest management. It could be postulated basing on the above model that for every 10 percent of converting forest in the basin into conventional cropping area, about 4-5 percent of RS could be annually increased.

CONCLUSION

This study is aimed at deriving the predictive models of reservoir sedimentation using drainage morphological factors and forest conversion in the northeast as case study. It is especally important in the northeastern Thailand where the soil is highly erodible and forest conversion for agricultural cropping is in serious condition. The mathematical statistical models for predicting reservoir sedimentation were formulated through multiple regression analysis using bottom survey data from 11 existing reservoirs to correlate with various hydrological, geomorphological and forest cover parameters. The results can be concluded as follows:

1. Among geomorphological factros used in deriving the relational function, only three parameters were selected as significant factors in predicting reservoir sedimentation (RS). These are annual inflow (Q in MCM), basin area (DA in sq.km), and basin relief ratio (Sr, %). The prediction equation is:

$$RS = e^{[-11.1354 + 2.8515 \ln Q - 0.0045 DA - 0.7229 Sr]}$$

2. When DA is disintegrated into 5 zones following the watershed area classification (WSC1-WSC5) proposed by Office of National Environmental Board of Thailand, the model to predict the increased sediment volume can be expressed as:

$$RS = {}^{[-6.671 + 2.5938 \ln Q + C]}$$

Where $C = (4.7585 Sr - 3.412 Si - 0.3782 WSA - 0.5421 WSC1)$

3. In order to obtain a model which can be used as a management tool for reducing RS by means of watershed rehabilitation, the forest cover parameter (For) was added. the prediction model becomes:

$$RS = e^{[-7.2348 + 2.5386 \ln Q - 0.0041 For. + K]}$$

where $K = (4.4442 Sr - 2.4077 Si - 0.307 WSA - 0.524 WSC1)$

4. This case study has been based on data from 11 reservoirs (15 periodical samples) only, which is not adequate for an axact mathematical statistical analysis. At least 30 sites of data should be used in order to satisfy a high level of statistical confidence. Unfortunately, only 11 reservoirs in the Norteast have been measured the increased sediment deposition.

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