Spatial and temporal trends in estimates of suspended sediment loads in the Yangtze River, China, 2001 to 2012

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Abstract. Suspended sediment (SS) in surface water play important roles in aquatic ecosystems and contributes to bottom material composition, water-column turbidity, and chemical constituent transport. Estimating loads of SS is complicated due to infrequent monitoring data, retransformation bias, data censoring, and non-normality. To obtain reliable unbiased estimates, the regression model Load Estimator (LOADEST) were applied to develop regression equations and to estimate total SS loads at three sites on the Yangtze River, China, from 2001 to 2012. Coefficients of determination (R^2) for the best-fit regression models for loads of SS indicated that the model for SS successfully simulated the variability in constituent loads at all studied sites. Because of variation in river discharge, the estimated seasonal loads fluctuated widely over the period of 2001 to 2012. Estimated loads of SS showed decreasing trends during the study period.

Keywords: Suspended sediment, LOADEST, Yangtze River.

1. INTRODUCTION

Suspended sediment (SS) in surface water play important roles in aquatic ecosystems and contributes to bottom material composition, water-column turbidity, and chemical constituent transport. Estimating loads of SS is complicated due to infrequent monitoring data, retransformation bias, data censoring, and non-normality. In this study, the regression model Load Estimator (LOADEST) were applied to estimate SS loads at three sites on the Yangtze River, China, from Jan. 2001 to Dec. 2012. We describe a procedure for estimation of constituent loads in rivers which have only sparse measurements of flow and water quality constituent concentrations. The primary goal of this study is to obtain reliable unbiased estimates of seasonal SS loads for the Yangtze River and demonstrate the utility of regression methods for estimation of seasonal SS loads from instantaneous samples.

2. DATA AND METHODS

2.1. Study area and data sources

Three stations were selected for analysis in this study: Yichang, Jianli and Luoshan stations. All these sites are located in the middle reaches of the Yangtze River.

2.2. Methods

Stream-water SS (ϕ) can be calculated using constituent concentration (C) and discharge (Q) integrated over time (t) :

$$C(t)Q(t)dt \quad (1)$$

Because the expense of collecting and analyzing samples for water quality constituents means it is often difficult to obtain continuous data, so the Equation 1can be written as:

$$L_T = \Delta t \quad {}_{i=1} L_i \qquad (2)$$

where L_T is an estimate of total load, L_i is an estimate of instantaneous load, n is the number of discrete points in time, and Δt is the time interval represented by the instantaneous load.

The FORTRAN Load Estimator (LOADEST) uses time-series streamflow data and constituent concentrations to calibrate a regression model that describes constituent loads in terms of various functions of streamflow and time, enabling a direct calculation of equation 2. Four methods are used in this program: Adjusted Maximum Likelihood

Estimation (AMLE), Maximum Likelihood Estimation (MLE), Linear Attribution Method (LAM), and Least Absolute Deviation (LAD). AMLE and MLE are suitable when the model calibration errors (residuals) are normally distributed; AMLE is the more appropriate method of the two when the calibration data set contains censored data (i.e. when data are reported as less than or greater than some threshold). LAM and LAD are useful when the residuals are not normally distributed. Because the input data in this study included censored data, and because the model calibration residuals were normally distributed within acceptable limits, the AMLE estimation method was selected in each site. The output regression model equations take the following general form (Runkel et al., 2004; Duan et al., 2013):

$$\ln(L_i) = a + b\ln Q + c\ln Q^2 + d\sin(2\pi dtime) + e\cos(2\pi dtime) + fdtime + gdtime^2 + \varepsilon \quad (3)$$

where L_i is the calculated load for sample i ; Q is stream discharge; $dtime$ is time, in decimal years from the beginning of the calibration period; ε is error; and a, b, c, d, e, f, g are the fitted parameters in the multiple regression model.

Some of the regression equations in this study did not include all of the above terms, depending on the lowest Akaike Information Criterion (*AIC*) values (Sakamoto et al., 1986).

$$AIC = 2k - 2\ln(L) \quad (4)$$

where k is the number of parameters in the statistical model, and L is the maximized value of the likelihood function for the estimated model. Combining the equations above, monthly and seasonal average SS loads were calculated. The seasons were considered as follows: winter (December, January, February); spring (March, April, May); summer (June, July, August); autumn (September, October, November).

3. RESULTS AND DISCUSSIONS

Coefficients of determination (R^2) for the best-fit regression models for loads of SS for the five studied sites (Table 1) ranged from 86.58 % to 92.59 % (site Jianli was the highest).

Table 1 Regression coefficients, coefficients of determination (R^2) and *AIC* for load models used to estimate SS at three sites in the Yangtze River basin, China, 2000-2012.

Site name	Regression Coefficient							R_2 (%)	*AIC*
	a	*b*	*c*	*d*	*e*	*f*	*g*		
Yichang	16.0827	2.2798	0.8783	0.4869	-0.6341	-0.2477	-0.0221	91.75	0.940
Jianli	18.6645	2.4332	-0.144	0.2403	0.1326	-0.1246	0.0101	92.59	0.682
Luoshan	18.9426	1.8725	3 0.0741	0.0360	0.3472	-0.0656	0.0098	86.58	0.874

Figure 1 shows time-series graphs comparing monthly average SS loads at all sites. Seasonal fluctuations in loads can clearly be seen for the period 2001 to 2012, even though the dates of peak discharge were not the same every year. Overall, estimated loads at Luoshan were larger than at the other sites, and there have been many large fluctuations at Wuchang site.

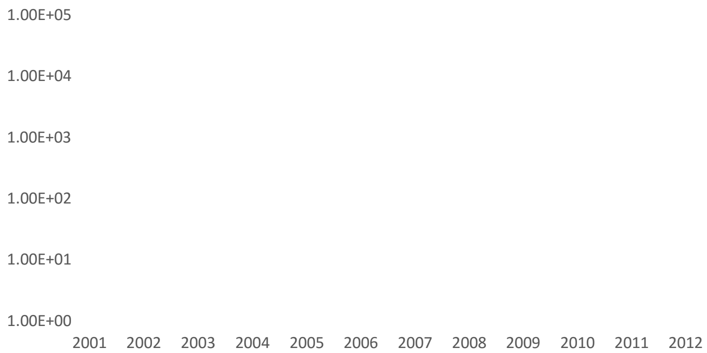

Figure 1 Estimated monthly average loads of SS at three sites on the Yangtze River, January 2001 through December 2012 (kg/day).

Figure 2 shows the estimated average loads of SS by month at all sites, 2001 to 2012, calculated by averaging the monthly averages for each month of the year (for example, the average of all January monthly averages, all February monthly averages, etc.). Obviously, the estimated average loads of SS in July, August and September had the larger loads compared with other months at all sites.

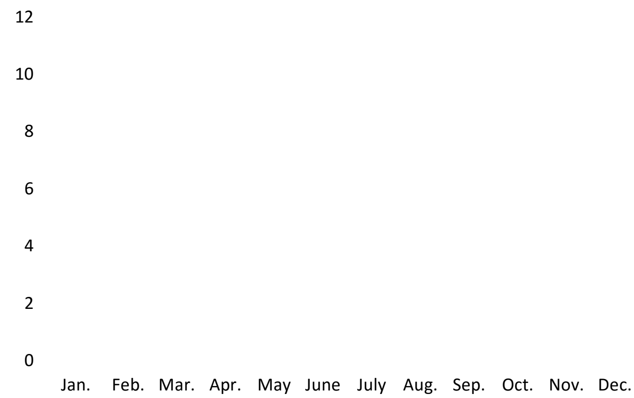

Figure 2 Estimated average loads of TN, TP and SS, by month, at three sites on the Yangtze River, January 2001 through December 2012 (kg/day).

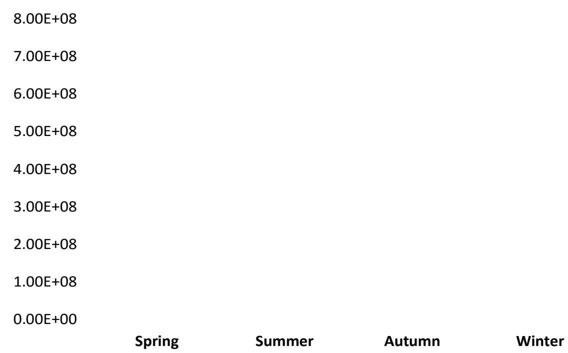

Figure 3 Estimated seasonal average loads of SS at three sites on the Yangtze River, January 2001 through December 2012 (kg/day).

Estimated seasonal loads of SS at three sites were highly variable between 2001 and 2012 in the Yangtze River, with the greatest loads occurring in the summer and the smallest loads occurring in the winter (Fig. 3), reflecting fluctuations in discharge as a result of the combined effects of seasonal runoff patterns, the exact timing of which vary from year to year.

4. CONCLUSIONS

The regression model Load Estimator (LOADEST) was used to develop regression equations and to estimate loads of suspended sediment (SS) at three sites on the Yangtze River, China, from January 2001 through December 2012, which illustrated how short records of daily waterflow and components concentration can be combined to obtain meaningful estimates of seasonal SS loads.

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