Suspended sediment yield prediction models for Costa Rican watersheds

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Abstract Measured mean annual suspended sediment yield in t km^{-2} (*SSTKM*) from 24 selected rural watersheds in Costa Rica was used to develop preliminary regional regression equations to predict/estimate *SSTKM* as a function of basin characteristics. The equation for the Atlantic basins included Mean Annual Soil Gross Erosion (*EROKM*) in t km^{-2}. The equation for the Pacific basins included Mean Annual Runoff (*QMM*) in mm and *EROKM*. The developed regression equations accounted for 89% and 93% of the variation of *SSTKM* in the Atlantic and Pacific basins respectively. The standard error of the estimate in t km^{-2} were 77 (coefficient of variation, *CV*, 34%) for the Atlantic slope and 37 (*CV* 31%) for the Pacific slope. Regression and diagnostics analysis indicated that the developed equations reliably estimate *SSTKM*.

Modelos de predicción de carga de sedimentos en suspensión para cuencas de Costa Rica

Resumen La carga media anual de sedimentos en suspensión en t km^{-2} (*SSTKM*) de 24 cuencas rurales de Costa Rica se utiliza para desarrollar modelos regionales de regresión para predecir preliminarmente *SSTKM* en función de las características de las cuencas. La ecuación de la Vertiente Atlántica incluyó la Erosión Media Anual Estimada en t km^{-2} (*EROKM*). La ecuación de la Vertiente del Pacífico incluyó la Escorrentía Media Anual en mm (*QMM*) y *EROKM*. Las ecuaciones desarrolladas explican un 89% y 93% de la variaciones de *SSTKM* en la vertiente Atlántica y Pacífica respectivamente. Los errores estándar de la estimación in t km^{-2} fueron de 77 (34% *CV*) para la Vertiente Atlántica y 37 (31% *CV*) para la vertiente Pacífica. Un diagnóstico de la regresiones desarrolladas indican que las ecuaciones estiman aceptablemente *SSTKM*.

INTRODUCTION

The development of regression equations to estimate/predict mean annual suspended sediment yield (*SSTKM*) is of special importance in the evaluation and planning of natural resources in the tropics. Not only it is important to have good estimation of *SSTKM* for ungauged basins with high water resources development potential, but also, it is necessary to have an instrument able to simulate the effect of land use changes on the basin hydrology for studies such as basin management, environmental impact analysis and land use planning.

The estimation/prediction models developed in this study are considered to be the first approximation and are based on the hypothesis that the variation of *SSTKM* from rural basins of Costa Rica can be explained by regression equations that include independent variables such as: (a) mean annual runoff and precipitation, which express the quantity of water capable of transporting sediment from eroded surfaces to stream channels; (b) drainage and road density as the index variable of the basin sediment delivery system; and (c) mean annual soil erosion in t km^{-2}, as the variable that synthesizes the effect of land use, topography, soil and climate of the basin.

METHODOLOGY

For the development of the regression equation a set of 24 gauged rural basins were selected. The selected basins met the following criteria: (a) they have complete streamflow records for water years 1981–1987, (b) they have urban land use not exceeding 15% of the total basin area, (c) they have streams with natural flow conditions, i.e. no significant hydraulic structures or diversions present, and (d) they are independent hydrologic units. The basins were subdivided regionally into 13 for the Atlantic slope and 11 for the Pacific slope. The basin areas range from 12 to 400 km^{-2} (Fig. 1, Table 1).

The data acquisition techniques employed and the information sources used for the most relevant variables selected in this study are described by Calvo & Quirós

Table 1 Selected basins and some bio-physical characteristics used in the development of the regression equation of mean annual suspended sediment yield in Costa Rica.

No.	Basin	Area (km^2)	*EROKM* ($t\ km^{-2}$)	Land use distribution in % Forest	Pasture	Perennial	Annual	*QMM* (mm)	*SSTKM* ($t\ km^{-2}$)
1	Piedras	12	489.0	42.80	57.20	0.00	0.00	3112.9	53.3
2	Piedras Negras	12.2	378.7	100.00	0.00	0.00	0.00	3893.1	81.9
3	Dos Bocas	12.9	350.5	12.70	87.30	0.00	0.00	2432.4	74.1
4	Blanco	50	1389.0	52.50	47.50	0.00	0.00	2475.3	849.4
5	La Muerte	53.3	620.3	47.90	52.10	0.00	0.00	3549.0	181.7
6	Macho	64	379.8	87.80	12.20	0.00	0.00	2069.1	47.1
7	Caño Negro	70	379.0	100.00	0.00	0.00	0.00	3367.3	88.1
8	Sarapiqui	72	354.0	92.10	7.90	0.00	0.00	3705.1	92.2
9	Peñas Blancas	123	489.8	100.00	0.00	0.00	0.00	4977.3	237.7
10	Toro	191	398.9	71.20	28.80	0.00	0.00	4027.0	222.1
11	Barbilla	212	856.5	98.80	1.20	0.00	0.00	3438.6	455.3
12	Frio	254	795.1	65.20	34.80	0.00	0.00	3189.0	232.5
13	Pacuare	367	669.5	95.40	4.60	0.00	0.00	2553.9	324.2
14	Salitral	26	680.0	61.90	38.10	0.00	0.00	1302.1	46.2
15	Salto	64	1246.0	31.20	68.80	0.00	0.00	527.3	32.0
16	Largarto	104	988.0	7.20	92.80	0.00	0.00	918.4	60.4
17	Pirris	115	1004.3	44.20	44.60	11.20	0.00	1247.7	113.9
18	Savegre	128	325.5	83.90	16.10	0.00	0.00	1474.0	60.8
19	Pejivalle	128	2085.0	9.20	90.70	0.00	0.00	1321.7	82.5
20	Colorado	128.2	972.0	38.60	60.70	0.00	0.70	901.3	36.7
21	Abangares	132	1220.3	0.00	100.0	0.00	0.00	1059.7	61.7
22	Naranjo	210	1144.0	74.20	25.80	0.00	0.00	3808.5	434.7
23	Chirripo	317.9	637.0	56.80	43.20	0.00	0.00	2148.1	128.8
24	Pacuar	322.7	2054.0	17.10	82.90	0.00	0.00	2051.1	272.6

Atlantic basins: nos 1–13; Pacific basins: nos 14–24.

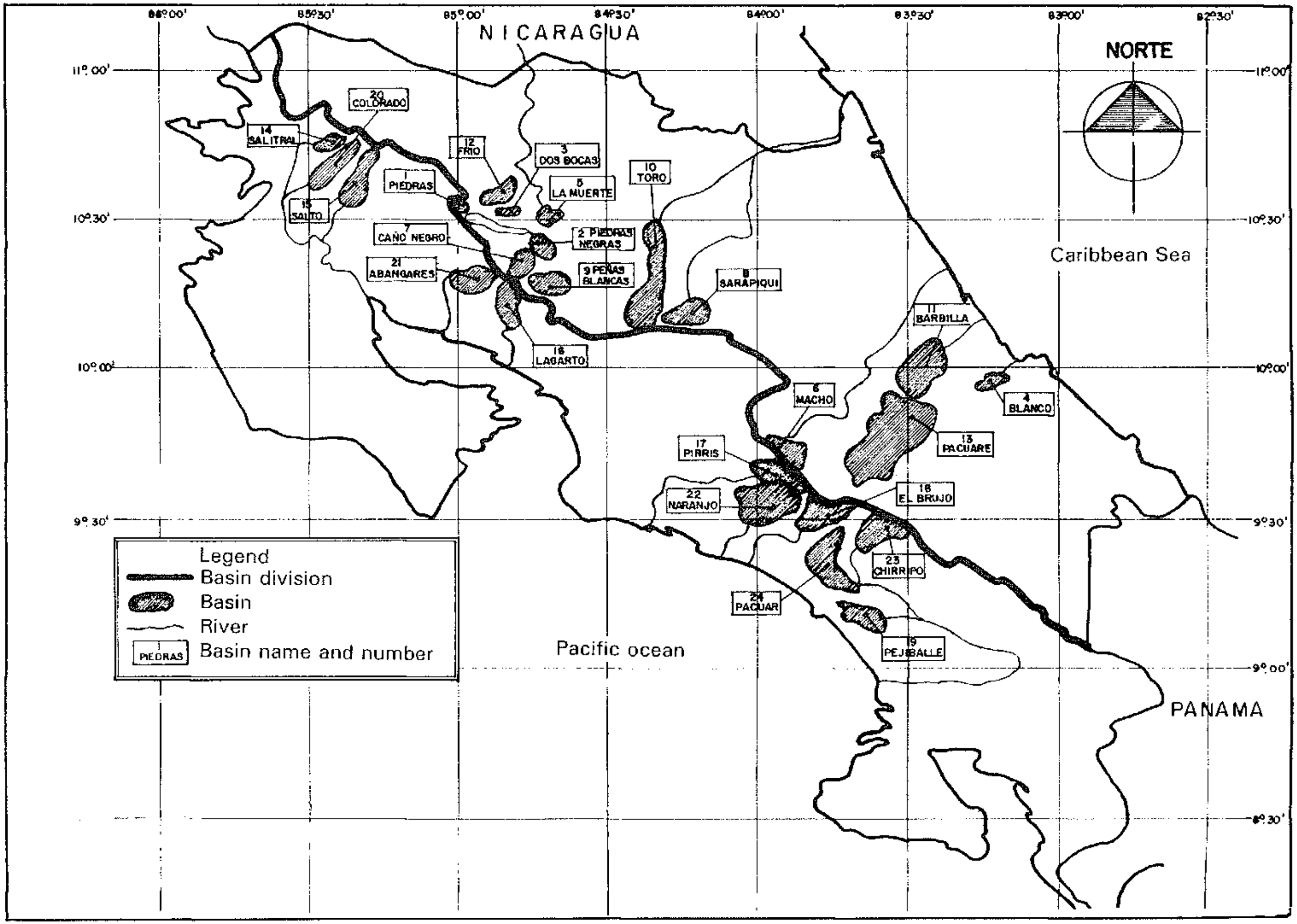

Fig. 1 Map of Costa Rica showing location of selected rural basins.

(1996). The most important variables used in this study are briefly as follows:

- *SSTKM* is the average of annual values of reported annual suspended sediment load for the water years 1981–1987 and is expressed in t km^{-2};
- mean annual runoff (*QMM*) and mean annual precipitation (*PRECI*) correspond to the same period and are expressed in mm;
- land use distribution in percentage was taken from the 1:200 000 Soil Erosion Map of Costa Rica prepared by FAO (1989) and based on LANDSAT 1984 images;
- mean annual soil erosion (*EROKM*, in t km^{-2}) was estimated according to the USLE equation and the FAO (1989) study;
- drainage and road density and basin morphological characteristics were measured using a digital curvimeter on 1:50 000 topographic maps.

Model development

The Statistical Analysis System (PC-SAS 6.03) and its regression procedures were used to carry out the data analysis (Freund & Littell, 1986). Data analysis was performed by region (Atlantic and Pacific slopes) because of the differences in climate. Since there are several independent variables to test for significance in each model, it was decided to run a correlation and stepwise regression analysis to facilitate the identification of good predictive independent variables.

Before developing the final regression equations, residual plots and validation analysis with the PRESS option (Freund & Littell, 1986) were conducted to check the least squares assumptions of normality and variance homogeneity.

RESULTS

Atlantic slope

The hypothesized association between *SSTKM* and *EROKM* was confirmed by the correlation and stepwise analysis. Table 2 summarizes the final regression equation. The standard error of estimate (*SEE*) and the coefficient of variation in percentage (*CV*) indicate that on the average *SSTKM* is estimated between ±77 t km^{-2} or with 34% of error. The R^2 indicates that the model explains 89% of the variation of *SSTKM*. This model is considered acceptable and could be used as a first approximation to simulate the effect of land use changes in the variation of *SSTKM*.

EROKM shows such a strong linear relationship with *SSTKM* that it only remains to identify other independent variables to improve the precision and further explain the variation of *SSTKM*.

Pacific slope

In this region the most significant variables for prediction of *SSTKM* were mean annual runoff (*QMM*) and *EROKM*. Table 3 summarizes the final regression equation.

Table 2 Variance analysis for the Atlantic slope regression equation.

Source	DF	Sum of squares	Mean square	*F* value	*Pr* > *F*
Model	1	529730.64	529730.64	88.50	0.0001
Error	11	65841.90	5985.62		
Corrected total	12	595572.54			

Root *MSE*: 77.36; *CV* (%): 34.21; *SSTKM* mean: 226.11; R^2: 0.89

Estimation of parameters:

Variable	DF	Estimated parameter	Standard error	*T* for H_0 Parameter = 0	*Pr* > |*T*|
Interception	1	-182.3833	48.4352	-3.766	0.0031
EROKM	1	0.7024	0.07466	9.407	0.0001

Regression equation *SSTKM* = -182.38 + 0.7024 (*EROKM*)
Note: DF = degrees of freedom, *Pr* = probabilitiy, *F* = the F statistic
T = statistic for testing the hypothesis that each coefficient is zero.

Table 3 Variance analysis for the Pacific slope regression equation.

Source	DF	Sum of squares	Mean square	*F* value	*Pr* > *F*
Model	2	143135.08	71567.54258	50.775	0.0001
Error	8	11275.95	1409.49498		
Corrected total	10	154411.04			

Root *MSE*: 37.54; *CV* (%): 31.05; *SSTKM* mean: 120.91; R^2: 0.93

Estimation of parameters:

Variable	DF	Estimated parameter	Standard error	*T* for H_0: Parameter = 0	*Pr* > |*T*|
Interception	1	-136.650289	33.13712599	-4.124	0.0033
QMM	1	0.127682	0.01327159	9.621	0.0001
EROKM	1	0.056106	0.02191807	2.560	0.0337

Regression equation *SSTKM* = -136.65 + 0.127 (*QMM*) + 0.056 (*EROKM*)

The proposed model explains 93% of the *SSTKM* variation with a standard error of estimate (*SEE*) of 37 t km^{-2} and a coefficient of variation (*CV*) of 31%. This model is also considered acceptable and could be used as a first approximation to simulate the effect of land use changes in the variation of *SSTKM* on the Pacific slope. Nevertheless the model is not practical for those basins that lack runoff information, which is usually the case for rural basins.

CONCLUSIONS AND RECOMMENDATIONS

The developed regression equations are intended to provide a suitable tool for the prediction of *SSTKM* for rural basins of Costa Rica. These equations must be considered as a starting point for further and more refined attempts to explain important relationships in the hydrology and suspended sediment yield characteristics of Costa Rica. The use of these equations must follow closely the techniques employed for measuring or estimating the included independent variables. Additional studies to improve the results and interpretations of this study are suggested by Calvo & Quiros (1996).

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