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Different approaches to estimate the sediment yield in a tropical watershed

Diferentes abordagens para estimar a produção de sedimentos em uma bacia hidrográfica tropical

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ABSTRACT

Several Sediment Delivery Ratio (SDR) models have been used to estimate Sediment Yield (SY), mainly in data-scarce and ungauged basins, such as in many regions of Brazil. However, it is difficult to choose the most suitable SDR model, mainly because of the lack of investigations of this approach using observed data. Here, we investigated the performance of five widely used SDR models (SDR_{EST}) to estimate sediment yield values (SY_{EST}) based on observed data in a tropical watershed. We used observed sediment yield values (SY_{OBS}) during September 2011 to July 2017 in three sub-basins of the Guariroba Basin, Midwestern Brazil. To estimate the average annual soil loss, we used the Revised Universal Soil Loss Equation. The SDR_{OBS} and SY_{OBS} ranged from 5.56 to 10.54% and 940.76 to 5,400.32 t yr^{-1}, respectively. The Williams and Berndt (1972) method presented the best performance, with a percent bias ranging from -2.34 to 3.30% in SRD estimation. Therefore, this model provided suitable SDR and SY estimates, and may be useful to estimate SY in other tropical data-scarce and ungauged basins.

Keywords: RUSLE; Sediment transport; Sediment yield; Soil erosion.

RESUMO

Vários modelos de taxa de entrega de sedimento (SDR) são utilizados para estimar a produção de sedimentos (SY), principalmente em bacias com dados escassos ou não medidos, como em muitas regiões do Brasil. No entanto, é difícil escolher o modelo SDR mais adequado, principalmente devido à falta de estudos que utilizam dados observados. Aqui, investigamos o desempenho de cinco modelos SDR amplamente utilizados (SDR_{EST}) para estimar os valores de produção de sedimentos (SY_{EST}) com base em dados observados em uma bacia hidrográfica tropical. Utilizamos valores de produção de sedimentos observados (SY_{OBS}) durante setembro de 2011 a julho de 2017 em três sub-bacias da Bacia do Guariroba, no Centro-Oeste do Brasil. Para estimar a perda média anual de solo, utilizamos a Equação de Perda de Solo Universal Revisada. Os valores de SDR_{OBS} e os SY_{OBS} variaram de 5.56 a 10.54% e 940.76 a 5,400.32 t ano^{-1}, respectivamente. O método Williams e Berndt (1972) apresentou o melhor desempenho, com porcentagem de tendência variando de -2.34 a 3.30% na estimativa SRD. Portanto, esse modelo forneceu estimativas SDR e SY adequadas, e pode ser útil para estimar SY em outras bacias hidrográficas tropicais com dados escassos ou não medidos.

Palavras-chave: RUSLE; Transporte de sedimentos; Produção de sedimentos; Erosão do solo.

INTRODUCTION

The removal of native vegetation for expansion of agricultural areas without the application of conservation practices compromises the ecosystems and it has the potential to cause economic and social losses, besides accelerating the soil erosion process (PIMENTEL et al., 1995). These losses occur from the effects of soil erosion on and off-site. The reduction of cultivable soil depth and a decline in soil fertility are on-site effects, while off-site problems arise because of the sedimentation downstream which reduces the capacity of rivers and drainage channels, increases the risk of flooding, and decreases useful life of reservoirs (MORGAN, 2005).

Several soil erosion and sedimentation investigations have been developed to better understand the link of soil loss within a drainage basin to the sediment yield (SY) at the basin outlet. It is still difficult to predict the SY, however there are tools that can help to better understand the sediment delivery process at basin scale (VENTE et al., 2007). The sediment delivery ratio (SDR) has been one of main approach used to quantify the sediment delivery process. SDR is defined as the fraction of gross erosion that is transported from a given basin in a given time interval (WALLING, 1983). Therefore, this approach consider various processes involved between on-site soil erosion and downstream sediment yield (VAN ROMPAEY et al., 2001).

Many SDR models have been developed (FERRO; MINACAPILLI, 1995) and used to estimate SY (WALLING, 1983). However, it is difficult to choose the most suitable SDR model for a specific basin, mainly because of the lack of investigations of this approach using observed data.

There have been significant advances in the studies of SDR in Brazil such as using models integrated to the Geographical Information System (GIS) for prediction of soil erosion and SDR (BESKOW et al., 2009). Other studies used the SDR approach to evaluate the effect of land-cover and land-use change on soil erosion and sediment delivery (ALATORRE et al., 2012; DIDONÉ; MINELLA; MERTEN, 2015) and its impacts on the reservoirs of hydroelectric power plant (BATISTA et al., 2017). However, few attentions have been given in the choose of SDR equations, leading to unrealistic SY estimation.

The aim of this study was to evaluate the performance of five widely used SDR models to estimate SY values based on observed data in a tropical watershed. We used observed sediment yield values obtained during the period from September 2011 to July 2017 in three sub-basins of the Guariroba Basin, Midwestern Brazil. To estimate the average annual soil loss, we used the Revised Universal Soil Loss Equation (RUSLE) (RENARD et al., 1997).

MATERIAL AND METHODS

Study area

This study was conducted in the environmental protection area of the Guariroba, an important watershed with an area of 360 km^2 located in the municipality of Campo Grande, Mato Grosso do Sul, Brazil. In this study we used a drainage area of 306.7, delimited considering the discharge gauge as the basin outlet (Figure 1). The Guariroba basin is the main water supplier for the municipality of Campo Grande, which has 863.982 inhabitants; therefore, it is crucial to better understand the hydrological and soil erosion processes that occur in this area.

The predominant land uses in the studied basin are pastures (74.3%) and eucalyptus (6.1%). The other land covers include undisturbed cerrado vegetation - Brazilian savanna (14.4%), riparian zones (3.2%), and areas with scarce vegetation (1.3%). The soil was classified according to the Brazilian Soil Classification System (SiBCS) as Orthic Quartzarenic Neosol - RQo with sandy texture (94.1%), Dystrophic Red Latosol - LVd with sandy loam texture (2.4%), and Hydromorphic Quartzarenic Neosol – RQg with sandy texture (3.5%).

According to the Köppen climate classification, the predominate climate type in the study area is Am, humid tropical, with dry winters (April through September) and hot and rainy summers (October through March) (ALVARES et al., 2013). The average annual temperature and precipitation are between 22 and 24°C, 1200 and 1400 mm, respectively (VIEIRA; SILVA, 2011). The elevation varies between 465 and 660 m, and the mean slope is 3.7%.

Soil and water conservation practices have been implemented since 2013 in the Guariroba basin, such as terraces, recovery of degraded areas, control and recovery of erosive processes, and recovery of the reservoir and desorption of watercourses. We have monitored three sub-basins of the Guariroba, called here as headwater (Ba1), medium (Ba2) and river mouth (Ba3), with area of 77.8, 162.5, and 306.7 km^2, respectively.

Estimated soil loss

Soil loss in the Guariroba Basin was calculated using the GISus-Model, a plugin for the ArcGIS Desktop Version 10.2, developed by Oliveira et al. (2015). GISus-M represents all RUSLE model's factors through raster data. The RUSLE model computes long-term average annual soil loss (A) multiplying six factors represented in Equation 1:

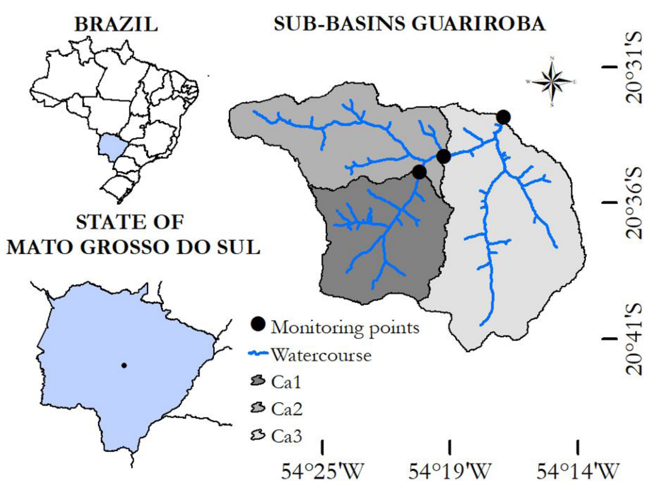

Figure 1. Location of the Guariroba Basin.

$$A = R.K.L.S.C.P \quad (1)$$

where A is the average annual soil loss (t ha^{-1} yr^{-1}); R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}); K is the soil erodibility factor (t h MJ^{-1} mm^{-1}); LS is the combined slope length (L) and slope steepness (S) factors (dimensionless); C is cover management factor (dimensionless); and P is supported practice factor (dimensionless).

Rainfall Erosivity (R-factor)

In this study, we used the R-factor map developed by Oliveira et al. (2012). To obtain the rainfall erosivity map for the State of Mato Grosso do Sul, the authors used 109 rain gauges and geostatistical techniques.

Soil Erodibility (K-factor)

We used values of the K-factor obtained in a previous study in the Guariroba Basin (ANACHE et al., 2016). They observed the soils RQo (horizons A and C) are sandy; the soils RQg (horizons H and C) are loamy-sandy, and soils LVd (horizons A and B) are clayey.

Topographic Factor (LS-Factor)

To calculate the LS factor, we used a Digital Elevation Model (DEM) with 10 meters of spatial resolution. This DEM input data was inserted in the GISus-M system that computed the LS-factor using the LS-TOOL proposed by Zhang et al. (2013). In the window of the LS-TOOL, the DEM layer was selected, and it was given output. The "Model" selected was the RUSLE because it better represents the slope steepness factor and considers the ratio of rill and interrill erosion (OLIVEIRA et al., 2015).

Cover and Management Factor (C-Factor) and Conservation Practices Factor (P-Factor)

We used the C-factor values obtained by experimental plot studies developed in Brazil (see OLIVEIRA; NEARING; WENDLAND, 2015). These C-factors were provided by soil erosion plots under natural rainfall and different land cover and land use in Brazil.

P-factor values were attributed according to Righetto (1998): without practices (1), contour farming (0.5), riparian vegetation recovery (0.25), and terrace (0.1).

Sediment monitoring

Monthly hydrosedimentological measurements of the water discharge and sediment concentration were carried out in three sub-basins of the Guariroba from September 2011 to July 2017. This monitoring provided us solid and liquid discharge data (for suspended sediments) throughout the year (dry and rainy period). The water discharge measurements were performed using a current meter in verticals spaced. The discharge was calculated by the half-section method using the product of the average speed for each vertical area of influence. Suspended load samplings were obtained for vertical integration using the techniques of Equal Width Increment (EWI), following (CARVALHO, 2008). Estimate of suspended load discharge is (Equation 2):

$$Qss = 0.0864.Qw.Cs \quad (2)$$

where Qss is the suspended-sediment discharge in t d^{-1}; Qw is the water discharge in m^3 s^{-1}; and Cs is the mean concentration of suspended sediment in the cross-section in mg l^{-1}.

SY values were calculated for each sub-basin using the discharge-weighted mean sediment concentration according to Ladegaard-Pedersen et al. (2017).

Sediment Delivery Ratio (SDR)

Observed sediment delivery ratio (SDR_{OBS}) values were computed from the ratio of sediment yield and gross soil erosion (Equation 3):

$$SDR_{obs} = \frac{SY_{OBS}}{E} \quad (3)$$

where SDR_{OBS} is the observed sediment delivery ratio (dimensionless); SY_{obs} is the annual sediment yield (t yr^{-1}), and E is the gross soil erosion (t yr^{-1}). The gross soil erosion (E) represents the loss in the entire basin in terms of t yr^{-1}, whereas the annual average loss (A) is calculated in terms of t ha^{-1} yr^{-1}.

The measurement of drainage basin area has been frequently used for computing SDR (VENTE et al., 2007) (Equation 4):

$$SDR = a.D^{-b} \quad (4)$$

where D is the drainage basin area; and a and b are correction factors related to the physical characteristics of the basin. The adjustment b variable has physical characteristics of sediment transport and is interrelated with the rain-flow phenomenon, and the negative sign signifies that with an area increase, the SDR decreases (CHAVES, 2010).

In the present study, we computed SY_{EST} from five models widely reported in the literature and compare with the SDR_{OBS} (Table 1).

RESULTS AND DISCUSSION

Estimated soil loss

Figure 2a shows that the R-factor increases from southwest to northeast in the Guariroba Basin, with an average of 9038 MJ mm ha^{-1} h^{-1} yr^{-1}. This value is similar to the average R-factor reported to Brazil and to the State of Mato Grosso do Sul of 8403 MJ mm ha^{-1} h^{-1} yr^{-1} (OLIVEIRA; WENDLAND; NEARING, 2013) and 9318 MJ mm ha^{-1} h^{-1} yr^{-1} (OLIVEIRA et al., 2012), respectively. According to Foster et al. (1981) this is a strong erosivity value. Therefore, it becomes clear the need to plan land use and land cover to minimize soil erosion processes.

Table 1. SDR models for calculate estimated SDR.

Models	Variables Description	Area (km²)	Source
$logSDR = 2.9 + 0.869.log - 0.854.log\,L$	R = difference between the average elevation of the basin and the outlet division elevation (m) L = length of watershed (m)	560	Maner (1958)
$SDR = 0.627.D^{0.403}$	D = slope main channel (%)	0.5-18	Williams and Berndt (1972)
$log\,SDR = 1.79 - 0.142.logA$	A = area (km²)	1-262	Renfro (1975)
$SDR = 0.42.A^{-0.125}$	A = area (km²)	2.6-1295	Vanoni VA (1975)
$SDR = 0.51.A^{-0.11}$	A = area (km²)	1.3-388.5	USDA (1979)

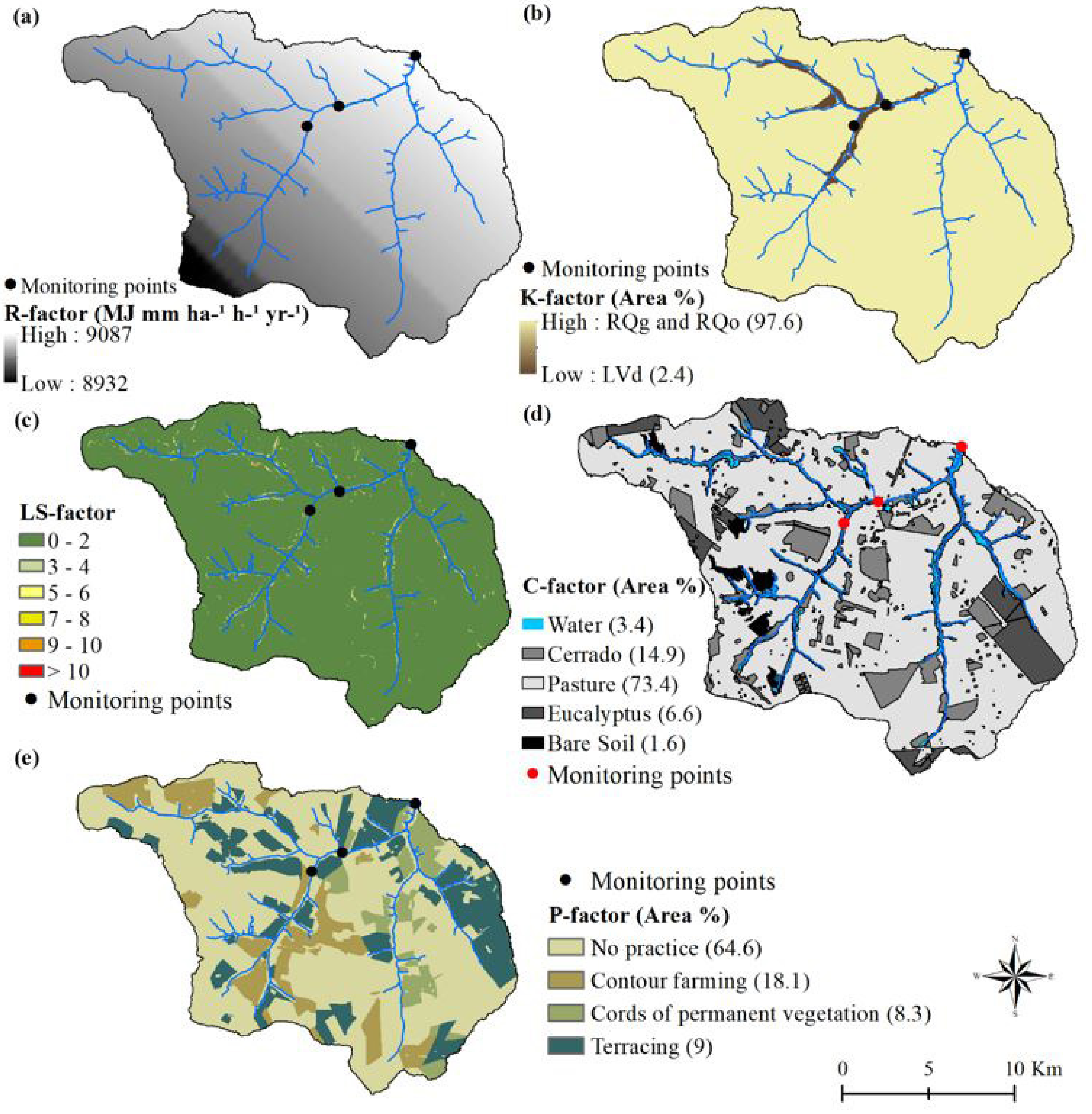

Figure 2. (a) R-factor; (b) K-factor; (c) LS-factor; (d) C-factor; (e) P-factor.

We found K-factor values for LVd of 0.028 t ha h ha^{-1} MJ^{-1} mm^{-1}, and RQg and RQo of 0.039 t ha h ha^{-1} MJ^{-1} mm^{-1} (Figure 2b). RQg and RQo, predominant soil in the Guariroba basin, presents sandy soils texture with a high susceptibility to soil erosion, mainly because the low soil aggregation. While clayey soils (located in flat areas) are less susceptible to soil erosion, because it allows greater stability of aggregates.

The average LS-Factors are 0.262, 0.314, and 0.297 for Ba1, Ba2, and Ba3, respectively (Figure 2c). We noted that LS-factor values increased from Ba1 to Ba2, but decreased from Ba2 to Ba3, indicating a raise in slope steepness in Ba2. The greatest LS-factor values are concentrated near to the channels.

Pasture is dominant in the three sub-basins, these land cover presented the greatest value of C-factor (Table 2). However, Ba1 presented the greatest area under bare soil, and Ba3 under eucalyptus (Figure 2d). Table 3 shows that there is a decreasing in the percentage of undisturbed cerrado vegetation area from the Ba1 to Ba3.

Conservation practices found in the studied basin were terrace, riparian vegetation recovery, contour farming, and without practice (Figure 2e). Approximately 65% of the Guariroba basin does not have soil and water conservation practices (Table 3).

The average annual soil loss estimated in the studied basin was 1.67 t ha^{-1} yr^{-1} (Figure 3). We noted that 35.1% of the study area presents very slight and slight soil loss (0-2 t ha^{-1} yr^{-1}) (Table 4). These soil loss values were observed in flat areas, with slopes steepness lower than 2%, and under the undisturbed cerrado vegetation.

Also, 30.4% of the area indicates moderate soil loss (5-10 t ha^{-1} yr^{-1}), characterized widely by areas with bare soil. High soil losses (10-20 t ha^{-1} yr^{-1}) represent 26% of area, with eucalyptus. Values of soil loss higher than 20 t ha^{-1} yr^{-1} are classified as very high, severe and very severe and occurs in 5.5% of the area; it is located high topographic factors (>2%) and areas with bare soil, pasture, and eucalyptus.

According to da Cunha, Bacani and Panachuki (2017) high values of soil loss are associated with areas under heavy anthropogenic action, such as those with secondary vegetation, eucalyptus trees, built areas, soil exposure in agriculture areas, roads, damaged pastures, burnt areas and erosive processes, which corroborate with our findings.

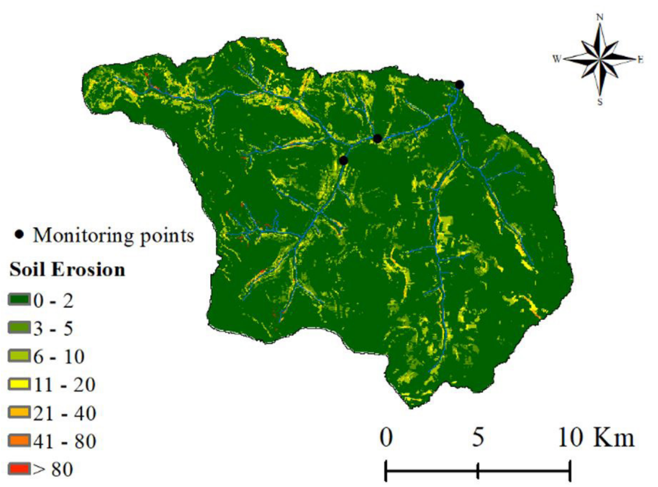

Figure 3. Soil loss across the Guariroba Basin. Values in t ha^{-1} yr^{-1}.

Estimated Sediment Delivery Ratio (SDR)

The estimated SDR have been used to estimate SY, which is transported to the watercourses of specific river basin. For this purpose, the physiographic parameters of the basin, as area, main-channel slope, the difference between the average elevation of the basin and the outlet division elevation, and the length of the basin, were obtained for the calculation of the SDR models (Table 5).

We found SY_{OBS} values of 940.76 t yr^{-1} (Ba1), 1,970.40 t yr^{-1} (Ba2), and 5,400.32 tyr^{1} (Ba3), tending to increase according to the area. This positive relation between drainage area and SY can be related to the presence of a well-developed vegetation cover, limited

Table 2. Classes of land use and cover, area of each sub-basin, and C-Factor.

Land cover and land use	Ba1 (%)	Ba2 (%)	Ba3 (%)	C-Factor
Eucalyptus	0.7	5.1	6.6	0
Cerrado	17.4	15.5	14.9	0.013
Wet area and water	3.4	3.6	3.4	0.020
Pasture	73.9	72.8	73.4	0.030
Bare Soil	4.5	2.9	1.6	1

Table 3. Classes of conservation practices, area of each sub-basin, and P-Factor.

Conservation Practices	Ba1 (%)	Ba2 (%)	Ba3 (%)	P-Factor
Terrace	11.0	6.5	9.0	0.1
Cordons of permanent vegetation	3.2	6.1	8.3	0.25
Leveled tracks	21.2	18.9	18.1	0.5
Without practice	64.4	66.6	64.6	1

Table 4. Location of the Guariroba Basin.

Erosion Class	Class limits (t ha^{-1} yr^{-1})	Area km²	%
Very slight	0-2	126.7	35.1
Slight	2-5	11.0	3.0
Moderate	5-10	109.6	30.4
High	10-20	93.8	26
Very high	20-40	15.8	4.4
Severe	40-80	2.2	0.6
Very severe	> 80	1.8	0.5

Source: (CARVALHO et al., 2000).

human disturbance, and a dominance of channel erosion over hillslope erosion processes such as sheet, rill and ephemeral gully erosion (VENTE et al., 2007).

We found SDR_{OBS} values of 6.23%, 5.56% and 10.54% to Ba1, Ba2, and Ba3, respectively (Table 6). Lu, Moran and Prosser (2006) also observed SDR value of 5.2% in a predominant flat area, showing few potentials to transport eroded sediment. We also noted that the steepest areas of Guariroba basin are the main sediment-producing zones. Further, average slope steepness and sediment production per unit area decrease with increasing basin size (see Figures 2c and 3). This occurs because there are more sediment storage locations between sediment source areas and the basin outlet.

We computed SDR_{EST} using five methods that take in account basin morphometric characteristics (Table 5). Comparing the SDR_{EST} obtained from these five methods with SDR_{OBS}, we found percent bias (PBIAS) ranging from -2.34 to 28.85% (Figure 4). The PBIAS is expected to be close to zero when the model is accurate to estimate the sediment delivery. Positive values indicate model overestimation bias and negative underestimation. Figure 4 show that all models overestimation SDR values, except to the Williams and Berndt (1972) method in the Ba3 (-2.34%). According to Moriasi et al. (2007) the PBIAS can be considered "very good" if PBIAS $< \pm$ 10%; "good", if 10% $\leq$ PBIAS $< \pm$ 15%; "satisfactory", if 15% $\leq$ PBIAS $< \pm$ 25%; and "unsatisfactory", if PBIAS $\geq \pm$ 25%. Therefore, we can classify the Williams and Berndt (1972) and Maner (1958) methods as "very good".

The Williams and Berndt (1972) method, which uses the slope of the main channel, presented the best performance to estimate SDR in all studied sub-basins. We found PBIAS values of 3.06%; 3.30% and -2.34%, respectively for Ba1, Ba2, and Ba3. The Maner (1958) method, whose intervening factor was the difference in basin elevation and length of basin, obtained the second-best result with PBIAS values of 10.86%, 9.92%, and 2.63%, respectively for Ba1, Ba2, and Ba3. Considering the PBIAS, we can classify the performance Williams and Berndt (1972) and Maner (1958) methods as "very good". PBIAS values obtained by methodologies that consider area of the basin, the main variable used to SDR estimation, (RENFRO, 1975; VANONI VA, 1975; USDA, 1979), ranged between 21.22 to 28.85 ("unsatisfactory"); 19.47 to 26.79 ("satisfactory"); 12.58 to 19.62 ("good"), respectively for Ba1, Ba2 and Ba3.

Our results indicated an overestimation of SDR values. According to Walling (1983), there is difficulty in establishing a general equation to estimate the SDR in a basin due to the high complexity of the delivery process of sediment and the need to evaluate the interrelation between their intervenient factors to adjust the equation.

The methodologies SDR_{OBS} do not correspond to a decreasing pattern in function, this makes that methodologies have values overestimated in Ba1 become underestimated in Ba3. The difference between the SDR_{OBS} and SDR_{EST} does not describe the actual situation because the prediction models consider few intervenient factors. Therefore, to develop the SDR model for a basin requires a detailed investigation of the characteristics, because most SDR models were developed based on limited measured sediment yield data to some specific regions.

We estimated SY from the different methodologies used to SDR_{EST}, in this case, there is an overestimation of SY through all five methods Ba1, Ba2, and Ba3, and underestimated in Ba3 for the methodologies of Renfro (1975) and Williams and Berndt (1972) (see Figure 5).

Williams and Berndt (1972) method showed the best performance to estimate SY, with PBIAS values of 17.89%, 21.32%; -17.74% ("satisfactory"), respectively for Ba1, Ba2, and Ba3. The other methodologies presented "unsatisfactory" PBIAS values that ranged from 63.41% to 293.02%, 82.08% to 178.42%, and 24.96% to 155.03%, respectively for Ba1, Ba2, and Ba3. The Williams and Berndt model explained the best results

Table 5. Physiographic parameters of each sub-basin.

Physiographic Parameters	Ba1	Ba2	Ba3
Basin area (km²)	77.80	162.50	306.67
Length of the basin (m)	11,419	13,469	18,643
Main channel slope (%)	0.88	0.78	0.64
Difference between the average elevation of the basin and the outlet division elevation (m)	100	105	120

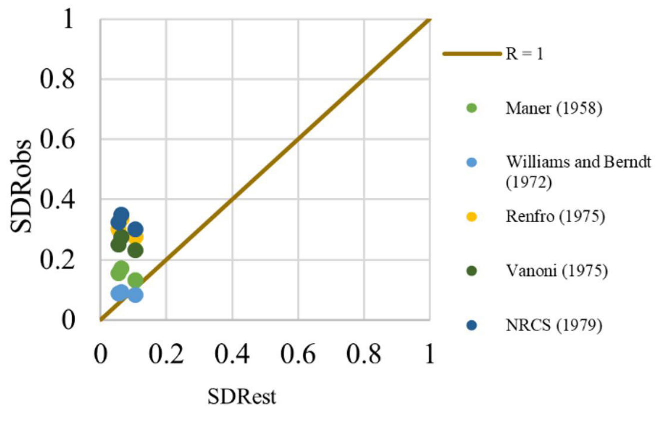

Figure 4. SDR_{EST} calculate for basin area for the Guariroba Basin. SDR dimensionless.

Table 6. SDR_{OBS} calculate for basin area for the Guariroba Basin.

	Area (ha)	A ($t\ ha^{-1}\ yr^{-1}$)	E ($ton\ yr^{-1}$)	SY ($ton\ yr^{-1}$)	SDR_{OBS} (%)
Ba1	7780	1.94	15,093.55	940.76	6.23
Ba2	16250	2.18	35,423.89	1,970.40	5.56
Ba3	30667	1.67	51,214.57	5,400.32	10.54

A is average annual soil loss ($t\ ha^{-1}\ yr^{-1}$); E is total annual gross erosion ($t\ yr^{-1}$); SY is observed sediment yield ($t\ yr^{-1}$); SDR_{OBS}= sediment delivery ratio.

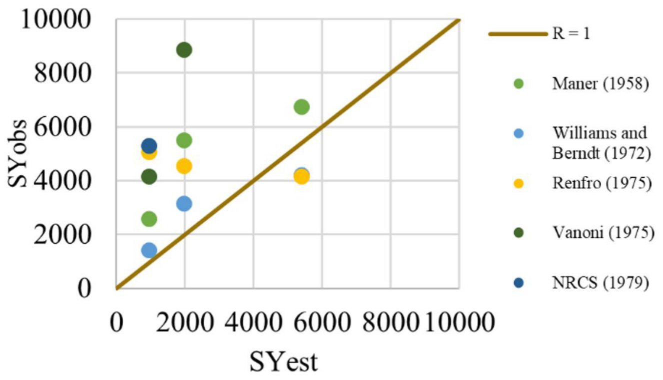

Figure 5. SY_{EST} calculate for basin area for the Guariroba Basin. Values in t yr^{-1}.

that represent the process of soil loss, displacement of the eroded sediments to the bodies of water, and its transport wash load and for the physiographic characteristics of the basin. Therefore, our results indicate that this method is the best alternative to estimate SDR and SY in the Guariroba basin. These findings may be also useful to land use planning and to estimate life expectancy of reservoirs that water supply municipality of Campo Grande considering different scenarios of land use and land cover change and changing climate.

CONCLUSION

In this study we evaluated performance of five widely used SDR models (SDR_{EST}) to estimate sediment yield values (SY_{EST}) based on observed data in a tropical watershed. To estimate the average annual soil loss, we used the Revised Universal Soil Loss Equation and observed values of sediment yield in three sub-basins of the Guariroba Basin (Ba1, Ba2, Ba3), Midwestern Brazil.

We estimated an annual average soil erosion of 1.67 t ha^{-1} yr^{-1}, and SDR_{OBS} and SY_{OBS} ranging from 5.56 to 10.54% and 940.76 to 5,400.32 t yr^{-1}, respectively. The performance of Williams and Berndt (1972) and Maner (1958) methods were classified as "very good", with percent bias in SRD estimation ranging from -2.34 to 3.30% and 2.63 to 10.86%, respectively. Our findings suggest these models (mainly the first one) provided suitable SDR and SY estimates and may be useful to estimate SY in other tropical data-scarce and ungauged basins.

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REFERENCES

ALATORRE, L. C.; BEGUERÍA, S.; LANA-RENAULT, N.; NAVAS, A.; GARCÍA-RUIZ, J. M. Soil erosion and sediment delivery in a mountain catchment under scenarios of land use change using a spatially distributed numerical model. *Hydrology and Earth System Sciences*, v. 16, n. 5, p. 1321-1334, 2012. http://dx.doi.org/10.5194/hess-16-1321-2012.

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVEZ, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift*, v. 22, n. 6, p. 711-728, 2013. http://dx.doi.org/10.1127/0941-2948/2013/0507.

ANACHE, J. A. A.; BACCHI, C. G. V.; PANACHUKI, E.; SOBRINHO, T. A. Assessment of methods for predicting soil erodibility in soil loss modeling. *Geociências (São Paulo)*, v. 34, p. 32-40, 2016.

BATISTA, P. V. G.; SILVA, M. L. N.; SILVA, B. P. C.; CURI, N.; BUENO, I. T.; ACÉRBI JÚNIOR, F. W.; DAVIES, J.; QUINTON, J. Modelling spatially distributed soil losses and sediment yield in the upper Grande River Basin - Brazil. *Catena*, v. 157, p. 139-150, 2017. http://dx.doi.org/10.1016/j.catena.2017.05.025.

BESKOW, S.; MELLO, C. R.; NORTON, L. D.; CURI, N.; VIOLA, M. R.; AVANZI, J. C. Soil erosion prediction in the Grande River Basin, Brazil using distributed modeling. *Catena*, v. 79, n. 1, p. 49-59, 2009. http://dx.doi.org/10.1016/j.catena.2009.05.010.

CARVALHO, N. O. *Hidrossedimentologia prática*. 2nd ed. Rio de Janeiro. Interciência, 2008.

CARVALHO, N. O.; FILIZOLA JÚNIOR, N. P.; SANTOS, P. M. C.; LIMA, J. E. F. W. *Guia de práticas sedimentométricas*. Brasília: Aneel – Agência Nacional de Energia Elétrica, 2000.

CHAVES, H. M. L. Relações de aporte de sedimento e implicações de sua utilização no pagamento por serviço ambiental em bacias hidrográficas. *Revista Brasileira de Ciência do Solo*, v. 34, n. 4, p. 1469-1477, 2010. http://dx.doi.org/10.1590/S0100-06832010000400043.

CUNHA, E. R.; BACANI, V. M.; PANACHUKI, E. Modeling soil erosion using RUSLE and GIS in a watershed occupied by rural settlement in the Brazilian Cerrado. *Natural Hazards*, v. 85, n. 2, p. 851-868, 2017. http://dx.doi.org/10.1007/s11069-016-2607-3.

DIDONÉ, E. J.; MINELLA, J. P. G.; MERTEN, G. H. Quantifying soil erosion and sediment yield in a catchment in southern Brazil and implications for land conservation. *Journal of Soils and Sediments*, v. 15, n. 11, p. 2334-2346, 2015. http://dx.doi.org/10.1007/s11368-015-1160-0.

FERRO, V.; MINACAPILLI, M. Sediment delivery processes at basin scale. *Hydrological Sciences Journal*, v. 40, n. 6, p. 703-717, 1995. http://dx.doi.org/10.1080/02626669509491460.

FOSTER, G. R.; MCCOOL, D. K.; RENARD, K. G.; MOLDENHAUER, W. C. Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation*, v. 36, p. 355-359, 1981.

LADEGAARD-PEDERSEN, P.; SIGSGAARD, C.; KROON, A.; ABERMANN, J.; SKOV, K.; ELBERLING, B. Suspended sediment in a high-Arctic river: An appraisal of flux estimation methods. *The Science of the Total Environment*, v. 580, p. 582-592, 2017. http://dx.doi.org/10.1016/j.scitotenv.2016.12.006. PMid:27986312.

LU, H.; MORAN, C. J.; PROSSER, I. P. Modelling sediment delivery ratio over the Murray Darling Basin. *Environmental Modelling & Software*, v. 21, n. 9, p. 1297-1308, 2006. http://dx.doi.org/10.1016/j.envsoft.2005.04.021.

MANER, S. B. Factor affecting sediment delivery rates in the Red Hills Physiographic Area. *Transactions - American Geophysical Union*, v. 39, n. 4, p. 669, 1958. http://dx.doi.org/10.1029/TR039i004p00669.

MORGAN, R. C. P. *Soil erosion and conservation*. 3rd ed. USA: Blackwell Publishing, 2005. p. 1-10.

MORIASI, D. N.; ARNOLD, J. G.; VAN LIEW, M. W.; BINGNER, R. L.; HARMEL, R. D.; VEITH, T. L. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, v. 50, n. 3, p. 885-900, 2007. http://dx.doi.org/10.13031/2013.23153.

OLIVEIRA, J. A.; DOMINGUEZ, J. M. L.; NEARING, M. A.; OLIVEIRA, P. T. S. A GIS-based procedure for automatically calculating soil loss from the universal soil loss equation: GISus-M. *Applied Engineering in Agriculture*, v. 31, n. 6, p. 907-917, 2015. http://dx.doi.org/10.13031/aea.31.11093.

OLIVEIRA, P. T. S.; NEARING, M. A.; WENDLAND, E. Orders of magnitude increase in soil erosion associated with land use change from native to cultivated vegetation in a Brazilian savannah environment. *Earth Surface Processes and Landforms*, v. 40, n. 11, p. 1524-1532, 2015. http://dx.doi.org/10.1002/esp.3738.

OLIVEIRA, P. T. S.; RODRIGUES, D. B. B.; SOBRINHO, T. A.; CARVALHO, D. F. C.; PANACHUKI, E. Spatial variability of the rainfall erosive potential in the state of Mato Grosso do Sul, Brazil. *Engenharia Agrícola*, v. 32, n. 1, p. 69-79, 2012. http://dx.doi.org/10.1590/S0100-69162012000100008.

OLIVEIRA, P. T. S.; WENDLAND, E.; NEARING, M. A. Rainfall erosivity in Brazil: a review. *Catena*, v. 100, p. 139-147, 2013. http://dx.doi.org/10.1016/j.catena.2012.08.006.

PIMENTEL, D.; HARVEY, C.; RESOSUDARMO, P.; SINCLAIR, K.; KURZ, D.; MCNAIR, M.; CRIST, S.; SHPRITZ, L.; FITTON, L.; SAFFOURI, R.; BLAIR, R. Environmental and economic costs of soil erosion and conservation benefits. *Science*, v. 267, n. 5201, p. 1117-1123, 1995. http://dx.doi.org/10.1126/science.267.5201.1117. PMid:17789193.

RENARD, K.; FOSTER, G. R.; WEESIES, G. A.; MCCOOL, D. K.; YODER, D. C. *Predicting soil erosion by water:* a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Washington: USDA, 1997.

RENFRO, G. W. *Use of erosion equations and sediment delivery ratios for predicting sediment yield, in present and prospective technology for predicting sediment yield and sources*. Washington: USDA, 1975. p. 33-45.

RIGHETTO, A. M. *Hidrologia e recursos hídricos*. São Carlos: EESC/USP, 1998.

USDA – UNITED STATES DEPARTMENT OF AGRICULTURE; NRCS – NATURAL RESOURCES CONSERVATION SERVICE. *Sediment sources, yields, and delivery ratios*. Washington: USDA, 1979. National Engineering Handbook, Section 3 – Sedimentation.

VAN ROMPAEY, A. J.; VERSTRAETEN, G.; VAN OOST, K.; GOVERS, G.; POESEN, J. Modelling mean annual sediment yield using a distributed approach. *Earth Surface Processes and Landforms*, v. 26, n. 11, p. 1221-1236, 2001. http://dx.doi.org/10.1002/esp.275.

VANONI VA. *Sedimentation engineering*. Manuals and reports on engineering practice. USA: ASCE, 1975. p. 745.

VENTE, J.; POESEN, J.; ARABKHEDRI, M.; VERSTRAETEN, G. The sediment delivery problem revisited. *Progress in Physical Geography*, v. 31, n. 2, p. 155-178, 2007. http://dx.doi.org/10.1177/0309133307076485.

VIEIRA, M.; SILVA, A. *Caderno Geoambiental das Regiões de Planejamento do MS*. Campo Grande: SEMAC, 2011.

WALLING, D. E. The sediment delivery problem. *Journal of Hydrology (Amsterdam)*, v. 65, n. 1-3, p. 209-237, 1983. http://dx.doi.org/10.1016/0022-1694(83)90217-2.

WILLIAMS, J. R.; BERNDT, H. D. Sediment yield computed with universal equation. *Journal of Hydrology (Amsterdam)*, v. 98, p. 2087-2098, 1972.

ZHANG, H.; YANG, Q.; LI, R.; LIU, Q.; MOORE, D.; HE, P.; RITSEMA, C. J.; GEISSEN, V. Extension of a GIS procedure for calculating the RUSLE equation LS factor. *Computers & Geosciences*, v. 52, p. 177-188, 2013. http://dx.doi.org/10.1016/j.cageo.2012.09.027.

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