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Environment

Solid discharge in a microbasin of the amazon region

Descarga sólida em microbacia da região amazônica

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ABSTRACT

The processes of water erosion and sedimentation occur naturally, however, they are being accelerated by human activities. Many microbasins lack information regarding the water resource, land use and occupation, as is the case of the Caiabi River microbasin, in which sediment production is potentiated by agricultural practices. The objectives of this study were to evaluate sediment transport in the Caiabi River and establish a rating curve for solid discharge from data obtained between 2018 and 2020, involving measurements of suspended sediment concentration, bed-load sediments and flow. The suspended and total solid discharges were established as a function of the flow rate through power, exponential, polynomial and linear equations, which parameters were adjusted by the method of least squares. The statistical evaluation of the rating curves indicated that the total solid discharge estimated from associations between suspended and bed load sediments is the one that best represents the transport of sediments in the Caiabi River while the exponential model offers the best fit to the observed data.

Keywords: Sediment transport; Silting; Forecast

RESUMO

Os processos de erosão hídrica e sedimentação ocorrem naturalmente, no entanto, têm sido acelerados pelas atividades humanas. Muitas microbacias carecem de informações quanto aos recursos hídricos e ao uso e ocupação do solo, caso da microbacia do rio Caiabi, na qual a produção de sedimentos é potencializada por práticas agrícolas. Os objetivos desse estudo foram avaliar o transporte de sedimentos no rio Caiabi e estabelecer uma curva-chave para a descarga sólida a partir de dados obtidos entre 2018 e 2020, envolvendo medições de concentração de sedimentos em suspensão, sedimentos de arrasto e vazão. As descargas sólidas em suspensão e total foram estabelecidas em função da vazão por meio de equações do tipo potência, exponencial, polinomial e linear, cujos parâmetros foram ajustados pelo método dos mínimos quadrados. A avaliação estatística das curvas-chaves indicou que a descarga sólida total estimada a partir de associações entre sedimentos suspensos e de arrasto é a que melhor representa o fluxo de sedimentos no rio Caiabi enquanto o modelo exponencial é o que oferece o melhor ajuste aos dados observados.

Palavras-chave: Transporte de sedimentos; Assoreamento; Previsão

1 INTRODUCTION

Water erosion and sedimentation processes occur naturally, despite the fact that they have been accelerated by human activities such as inadequate land use, deforestation, urbanization, agricultural activities, and changes in water courses (SHUZHEN *et al.*, 2002; SILVA *et al.*, 2016; BUSSI *et al.*, 2021). Thus, the migration of springs, removal of the fertile soil layer in agricultural areas, changes in surface runoff conditions, interference in water quality, damage to bridges and canals, among other problems can be observed (CARVALHO, 2008).

In hydrographic basins, the investigation of the production and transport of sediments can be carried out from direct measurements in water courses. Nevertheless, such methodology has technical limitations in extreme events and does not allow continuous observation. In this sense, adopting mathematical models - such as rating curves, is an interesting alternative, as it makes it possible to estimate data as for example, sediment concentration and solid discharge from a variable which is easier to monitor as well as its flow (MENEZES *et al.*, 2021).

Currently, most hydrosedimentometric studies are related to large hydrographic basins, such as the Amazon basin (LATUF & AMARAL, 2015; BERNINI *et al.*, 2016; YU *et al.*, 2017; MONTANHER *et al.*, 2018), thus, many smaller basins lack concrete information regarding their peculiarities (MACHADO *et al.*, 2012; LATUF *et al.*, 2019; PRADO *et al.*, 2021). Taking this information into account, the Caiabi River microbasin- which is part of the Teles Pires River basin and where agribusiness has been responsible for major changes in the forms of land use and occupation in the last 30 years (ZAIATZ *et al.*, 2018) and several hydropower projects, has recently started operating (GALLARDO *et al.*, 2017).

Given the above, the objectives of the present study were to evaluate sediment transport in the Caiabi River and establish a rating curve for solid discharge from data obtained between 2018 and 2020, involving measurements of suspended sediment concentration, bed load sediments and flow.

2 METHODOLOGY

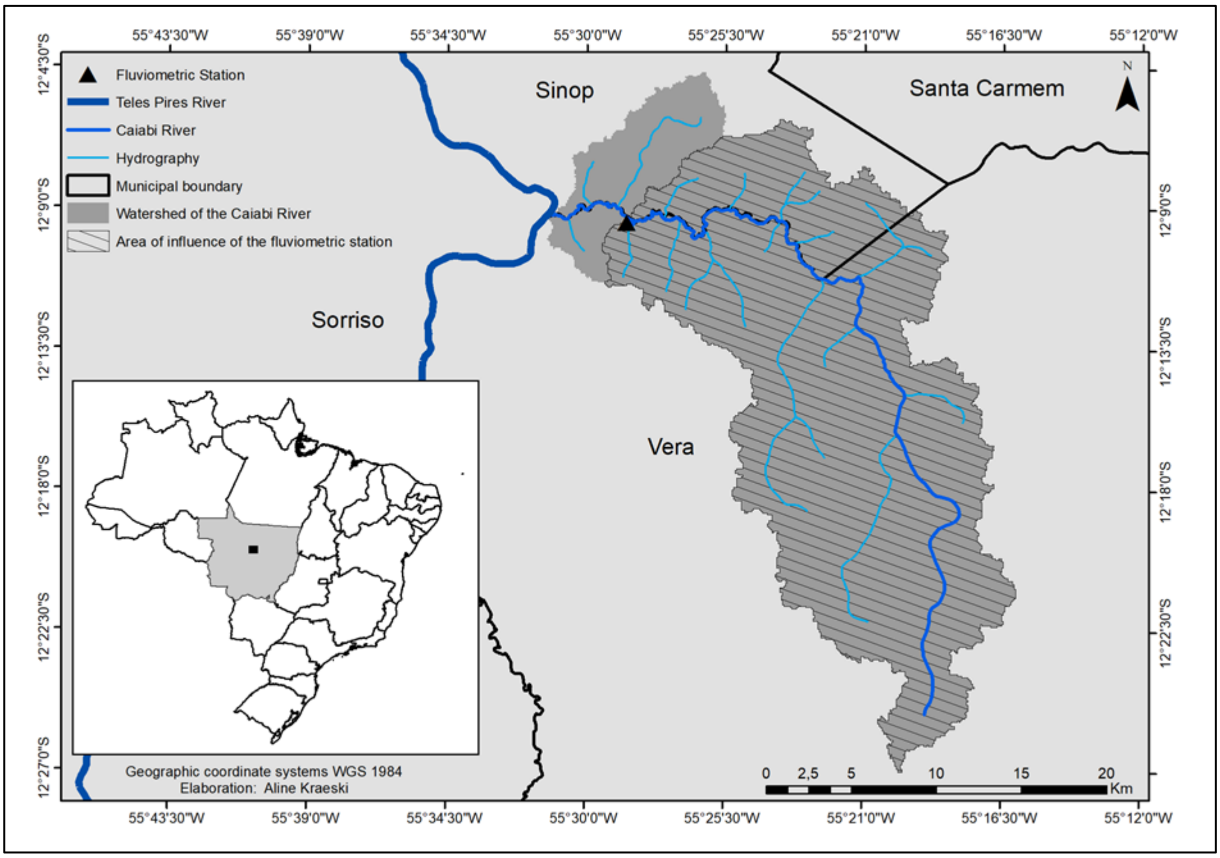
2.1 Study area

The Caiabi River watershed is located in the middle north region of the state of Mato Grosso, in the municipalities of Vera and Sinop (Figure 1), covering both the Amazon basin and the Cerrado-Amazon ecotone (MARIMON *et al.*, 2006). It counts on area of 489.3 km², relief of undulating plan (SANTOS *et al.*, 2018) and a main river with 57.7 km whose margins present riparian forest along its entire length (ANDRIETTI *et al.*, 2015). The average annual rainfall in the region is approximately 2,000 mm, with rainfall concentrated in the summer / autumn and water deficiencies in the winter / spring, especially between June and August, a climate classified as Aw' according to Köppen's method (SOUZA *et al.*, 2013).

Considering the accessibility criteria, representativeness of the point in question, river width and vegetation density (SANTOS *et al.*, 2001), the control section (fluviometric station) was established 5.3 km from the convergence of the Caiabi River with the Teles Pires River. As a result, this study considered just the watershed area and the length of the main river before the section, 436.1 km³ and 52.4 km, respectively (Figure 1).

Sedimentometric monitoring took place between December 2018 and February 2020. The campaigns consisted of measuring the flow and collecting samples of suspended sediments and bed load sediments. The number of measurements was higher in the rainy season, as recommended by WMO (1994).

Figure 1 – Location of the Caiabi River watershed and its control section

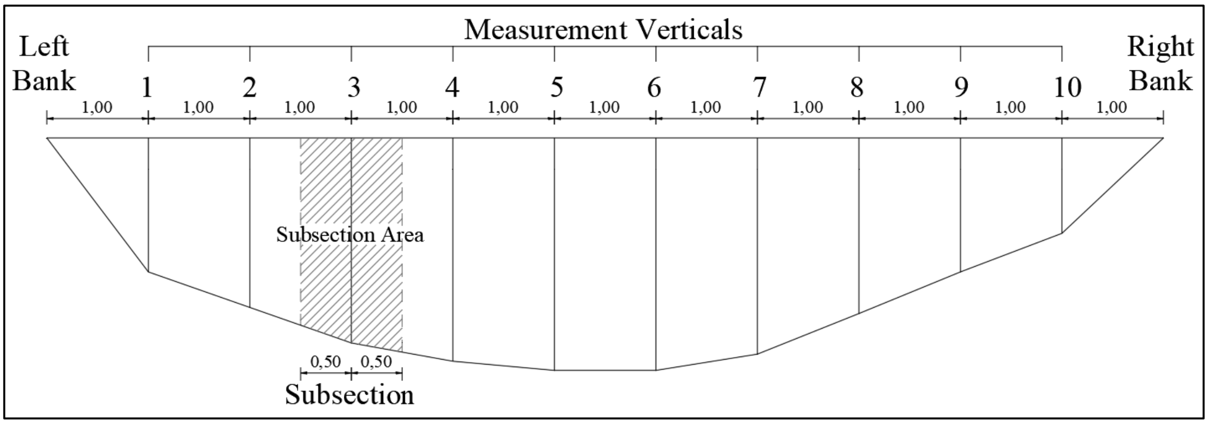


Source: Author (2020)

2.2 Net flow determination

In order to determine the net flow, the half-section method- which consists of multiplying the average speed by the area of pre-established subsections- was used (SANTOS *et al.*, 2001). During the monitoring, the width of the river varied between 10 m and 12 m, thus, the measurement verticals maintained the spacing of 1 m (Figure 2). The current speeds were measured with the aid of a hydrometric windlass, model MLN-7 of the JCTM brand.

Figure 2 – Distribution of measurement verticals / subsections in the average profile of the Caiabi River control section



Source: Author (2020)

2.3 Sediment sampling

The sampling of suspended sediments was performed using the method of equal increment of width - IIL (CARVALHO, 2008) in the same verticals established in the measurement of the liquid flow (Figure 2). The US DH-48 sampler with the 3/16” nozzle ("K = 0.4 ") was used, which presented the best performance in the sampling efficiency tests. Previous studies on the Caiabi River found average concentrations below 20 mg L^{-1} (ANDRIETTI *et al.*, 2016), thus, the collection volume was set at 10 liters, as recommended by WMO (1994). In this case, sub-samples of each vertical were combined into a single sample, called “composite”, representative of the entire section. In parallel, in order to outline the profile of the concentration and flow of suspended sediments in the section, “extra” samples of 1 liter were collected in each vertical, which were analyzed individually.

The sampling of bed load sediments was carried out in 5 verticals (1, 3, 5, 7 and 9) with the aid of a US BLH-84 sampler, which contains a bag where the sediment dragged in the bed is retained. The sampling time in each vertical was 30 minutes, in order to collect enough material to determine the dry weight and granulometric analysis (CARVALHO, 2008). All suspended and bed load sediments samples were identified and transported to the Hydraulics Laboratory at the Federal University of Mato Grosso, Sinop campus.

2.4 Laboratory analysis

To determine the concentration of suspended sediment in each sample, a gravimetric method was used, following the rules and procedures proposed by APHA (2012). With the aid of vacuum pumps, the samples were filtered through membranes with an opening equal to 0.45 micrometers dried in an oven at 105 ºC for 24 hours, before and after filtration, cooled in a desiccator and weighed. Finally, the concentration in each sample was calculated using Equation 1:

$$C_{ss} = \frac{m_2 - m_1}{V} \tag{1}$$

Where C_{ss} is the concentration of suspended sediment (mg L^{-1}), m^2 is the dry mass of the membrane with sediment (mg), m_1 is the dry mass of the clean membrane (mg) and V is the sample volume (L).

The bed load sediments samples were drained, the organic matter removed and the solid material transferred in aluminum capsules for drying in an oven at 105 ºC for 72 hours. The dry material was weighed and sieved in a series of sieves with openings equal to 8 mm, 4 mm, 2 mm, 1 mm, 500 µm, 250 µm, 125 µm and 63 µm for granulometric analysis (ABNT, 2016).

2.5 Calculation of solid discharge

The suspended solid discharge measured by the composite samples and bed load discharge were estimated with Equations 2 and 3, respectively (WMO, 1994):

$$Q_{ss} = 0{,}0864 \,.\, Q \,.\, C_{ss} \tag{2}$$

Where Q_{ss} is the suspended solid discharge in the section by composite samples (t d^{-1}), Q is the flow in the section (m^3 s^{-1}) and C_{ss} is the concentration of suspended sediment in the sample (mg L^{-1}).

$$Q_{bl} = \left(\frac{1440\ .\ m\ .\ l}{E_{eq}\ .\ n\ .\ l_{eq}\ .\ T}\right) \div 1000 \tag{3}$$

Where Q_{bl} is the bed load discharge (t d^{-1}); m is the total dry mass sampled (kg); l is section width (m); E_{eq} is the sampling efficiency of the equipment, set here as 1; n is the number of verticals sampled; leq is the width of the sampler mouth (m), in this case, equal to 0.075 m; and T is the sampling time for each vertical (min).

With the extra samples in the verticals, the suspended solid discharge in each subsection was estimated, separately:

$$q_{ss} = 0{,}0864\ .\ q\ .\ C_{ss-v}.\ l_{inf} \tag{4}$$

Where q_{ss} is the vertical suspended solid discharge (t d^{-1}), q is the vertical flow (m^3 s^{-1}); $C_{(ss\text{-}v)}$ is the vertical sediment concentration (mg L^{-1}); and linf is the width of influence of the vertical or width of the subsection (m), in this case, equal to 1 m.

According to Carvalho (2008), Q_{ss} can also be estimated by adding qss (Equation 5). Thus, in parallel, the suspended solid discharge was calculated from the extra samples in the verticals:

$$Q_{ss-v} = \sum_{1}^{n} q_{ss} \tag{5}$$

Where $Q_{(ss\text{-}v)}$ is the suspended solid discharge by extra samples in the verticals (t d^{-1}), q_{ss} is the suspended solid discharge in the vertical (t d^{-1}) and n is the number of sampled verticals.

The total solid discharge was estimated by associating the bed load discharge both with solid suspended discharges measured by composite samples (Q_{ts}, in t d-

^{1}) and with solid suspended discharges measured by extra samples in verticals ($Q_{(ts-v)}$, in t d^{-1}), Equations 6 and 7, respectively:

$$Q_{ts} = Q_{ss} + Q_{bl} \tag{6}$$

$$Q_{ts-v} = Q_{ss-v} + Q_{bl} \tag{7}$$

2.6 Rating curves of solid discharge

The data were paired establishing the solid discharges as a function of the net flow (Q_{ss}, Q_{ts}, $Q_{(ss-v)}$, $Q_{(ts-v)}$, Q_{bl} = f (Q)). The power model is the most suitable and used in the elaboration of sediment rating curves, however, there are studies that have obtained good results by testing other adjustment models, such as Bellinaso *et al.* (2007), Latuf; Amaral (2015); De Girolamo *et al.* (2015). Thus, power model curves ($Q_{(s...)} = a\ Q^{b}$), exponential ($Q_{(s...)} = a\ e^{bQ}$), grade 2 polynomial with intersection defined by the origin ($Q_{(s...)} = a\ Q^{2} + b\ Q$) and linear with intersection defined by the origin ($Q_{(s...)} = a\ Q$), whose parameters a and b were adjusted by the least square's method.

In addition to the coefficients of determination (R^2) and Pearson's correlation (r), three more performance indicators were used to evaluate the models: Nash-Sutcliffe efficiency index (Equation 8), root of the mean square error (Equation 9) and absolute mean deviations (Equation 10).

$$NSE = 1 - \frac{\sum_1^n (Q_{s-obs} - Q_{s-est})^2}{\sum_1^n (Q_{s-obs} - \bar{Q}_{s-obs})^2} \tag{8}$$

$$RMSE = \sqrt{\frac{\sum_1^n (Q_{s-obs} - Q_{s-est})^2}{n}} \tag{9}$$

$$D(\%) = \frac{\sum_1^n \left| \frac{(Q_{s-est} - Q_{s-obs})}{(Q_{s-est})} \right|}{n} \times 100 \tag{10}$$

Where $Q_{(s\text{-}obs)}$ is the observed solid discharge (t d^{-1}), $Q_{(s\text{-}est)}$ is the solid discharge estimated by the model (t d^{-1}), $Q_{(s\text{-}obs)}$ is the average of the values observed solid discharge (t d^{-1}) and n is the number of observations.

The Nash-Sutcliffe (NSE) index, in addition to being widely used, is considered an important criterion for the evaluation of hydrological models (OUELLET-PROULX *et al.*, 2016; GHAFARI *et al.*, 2017; AHN & STEINSCHNEIDE, 2018; AR *et al.*, 2018). Its value ranges from $-\infty$ to 1, where 1 indicates perfect fit of the model, NSE > 0.75 indicates good fit, 0.36 < NSE < 0.75 indicates satisfactory fit and NSE < 0.36 indicates unsatisfactory fit (MOTOVILOV *et al.*, 1999).

The root of the mean square error (RMSE) measures the accuracy of the models based on the magnitude of the errors, presenting high sensitivity to the divergences between estimated and observed values (WANG & LU, 2018). The mean absolute deviations (D) measure trends in the estimates produced by the models in relation to the observed data (HOROWITZ, 2003). For these two statistics, the lower the resulting value, the greater the accuracy of the model.

3 RESULTS AND DISCUSSION

3.1 Hydrosedimentological characterization

First, it was evaluated how the concentrations and, consequently, the solid discharges responded to the two conducts adopted for the sampling of suspended and composite sediments, for the same flows (Table 1). In Figure 3, taking the 45º line as a parameter of perfect correlation, it is observed that the concentrations of the extra samples underestimated the concentrations of the composite samples, given the considerable range of points in the upper part of the line. Although composite sampling is more used in practice, extra sampling helped to outline the section's hydrosedimentological profile through the individual analysis of each vertical (Figure 5) and expanded the study of rating curves by offering a parallel method for calculating discharge solid.

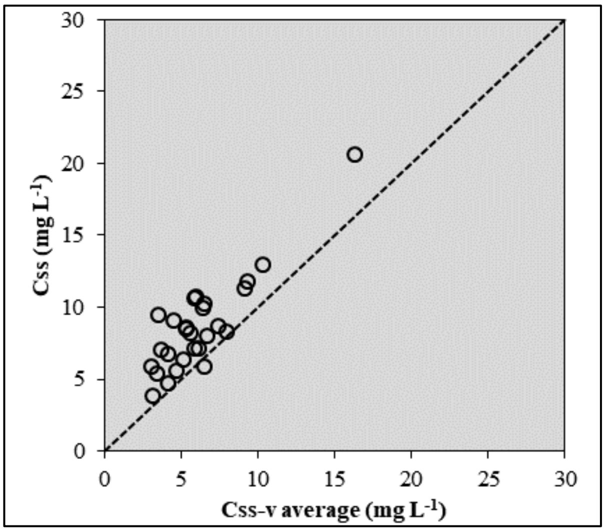
For practical reasons, most of the sediment rating curves start from correlations with the flow, however, variables such as soil cover, morphology and climate can be decisive with regard to the production and carrying of sediments (ALMAGRO *et al.*, 2019; COLMAN *et al.*, 2018; GHAFARI *et al.*, 2017), directly influencing the estimated values. The hydrosedimentological monitoring of the Caiabi River microbasin is something recent, therefore, the discussion on this theme is still limited by the absence of serial data. Comparing the data observed in the Caiabi River (Table 1) with those of other rivers, located in basins with similar or different characteristics, shows that the establishment of standards is something really complex.

Table 1 – Patterns of hydrosedimentological variables observed in the control section of the Caiabi River from 2018 to 2020

Variable	**Minimum**	**Maximum**
Elevation(m)	1,98	3,52
Q ($m^3.s^{-1}$)	5,95	16,14
C_{ss} ($mg.L^{-1}$)	3,85	20,59
C_{ss-v} ($mg.L^{-1}$)	3,02	16,29
Q_{ss} ($t.d^{-1}$)	2,21	28,71
Q_{ss-v} ($t.d^{-1}$)	1,55	22,82
Q_{bl}($t.d^{-1}$)	0,01	1,06
Q_{ts} ($t.d^{-1}$)	2,33	28,87
Q_{ts-v} ($t.d^{-1}$)	1,90	23,08

In where: Q: Flow rate; C_{ss}: concentration of suspended sediments in composite samples; $C_{(ss-v)}$: concentration of suspended sediment in extra samples in verticals; Q_{ss}: solid discharge in suspension by composite samples; $Q_{(ss-v)}$: solid discharge in suspension by extra samples in verticals; Q_{bl}: bed load discharge; Q_{ts}: total solid discharge by composite samples and bed load; $Q_{(ts-v)}$: total solid discharge by extra vertical samples and bed load.

Figure 3 – Relationship between average concentrations in verticals (**$C_{ss\text{-}v\ average}$**) and concentrations in the composite samples (**C_{ss}**) in the control section of the Caiabi River from 2018 to 2020



Source: Authors (2020)

Peixoto *et al.* (2018) found C_{ss} between 7.25 and 16.25 mg L^{-1}, for flows between 33.78 and 48.25 m^3 s^{-1}, in upstream sampling of three small hydroelectric plants on the Ivaí River, located in a predominantly agricultural region. Watanabe *et al.* (2018) found C_{ss} between 5 and 35 mg L^{-1} and Qss between 2.18 and 8.15 t d^{-1}, for flows between 1 and 3.5 m^3 s^{-1}, in two sub-basins of the Mutum-Parana River named for the predominant occupation as "Forest" and "Livestock", registering the lowest sediment input in the "Forest" sub-basin. Latuf *et al.* (2019) found average C_{ss} equal to 45.1 mg L^{-1} and average Q_{ss} equal to 49.9 t d^{-1} in the Machado River basin, which accounts for 41.7% of its area occupied by forest and the remainder by areas mainly anthropized by coffee cultivation. It is noted that the concentrations and solid discharges observed in the Caiabi River are close to those of the first two studies and different from the third, despite the similarities in land occupation.

Although the climatic aspect of the Caiabi River microbasin results in hydro-sedimentological variables of considerable amplitude, other basins presented much larger amplitudes, mainly during precipitation events. During the dry season of the Piranhas River, located in the northeastern semiarid, Garrido *et al.* (2018) found C_{ss} between 2.53 and 8.80 mg L^{-1} and Q_{ts} between 11.82 and 27.55 t d^{-1}, for flows between 9.68 and 10.76 m^3 s^{-1}. With the onset of precipitation, dry and exposed soil favored the carrying of sediments, resulting in C_{ss} between 15.62 and 161.99 mg L^{-1} and Q_{ts} between 26.16 and 488.66 t d^{-1}, for flows between 7.31 and 25.06 m^3 s^{-1}. In the low course of the Cabaçal River, characterized by the formation of wetlands and alluvies, Lima *et al.* (2018) observed C_{ss} between 120 and 630 mg L^{-1} and Qss between 97.67 and 1,589.30 t d^{-1}, for flows between 3.34 to 78.86 m^3 s^{-1}. In the Acre River, located in a region of significant seasonal variation and increasing deforestation, Latuf & Amaral (2015) found C_{ss} between 27 and 822 mg L_{-1} and Qss between 71.3 and 165,052.3 t d^{-1} for flows between 21.9 and 2,324.0 m^3 s^{-1}. On the Saint John River, where 83% of the basin's area is occupied by forest, Ouellet-Proulx *et al.* (2016) found an average C_{ss} of 54.34 mg L^{-1}, with a peak of 1,650 mg L^{-1}, for an average flow of 697.00 m^3 s^{-1}, with a peak of 2,950 m^3 s^{-1}. In the Riacho Fundo stream, located in an area of intense urbanization, Aquino *et al.* (2018) found a maximum C_{ss} of 11,340 mg L^{-1} and a maximum flow of 64.44 m^3 s^{-1}. On the Celone River, in a mountain region, De Girolamo *et al.* (2015) found a maximum C_{ss} 7,130 mg L^{-1} for a maximum flow of 23.50 m^3 s^{-1}. In a historical series of data from contributory basins in Lake Tana, a region with a monsoon climate, Moges *et al.* (2016) observed C_{ss} of up to 14,000 mg L^{-1}.

It is observed that the sedimentary input measured in the Caiabi River was relatively low, corroborating the statement by Andrietti *et al.* (2016) that the waters of this river are of good quality thanks to the presence of native vegetation, conservation of riparian forest and dilution effect of tributaries. Morphologically, the wavy-plane relief is also a factor to be considered, since it makes the watershed less susceptible to erosive processes, regulating soil loss and the carrying of sediments to the exudatory, even with the present agricultural practices.

Figure 4 illustrates the average hydrosedimentometric profiles outlined from the flow, sediment concentration, solid discharge in suspension and bed load discharge from each vertical.

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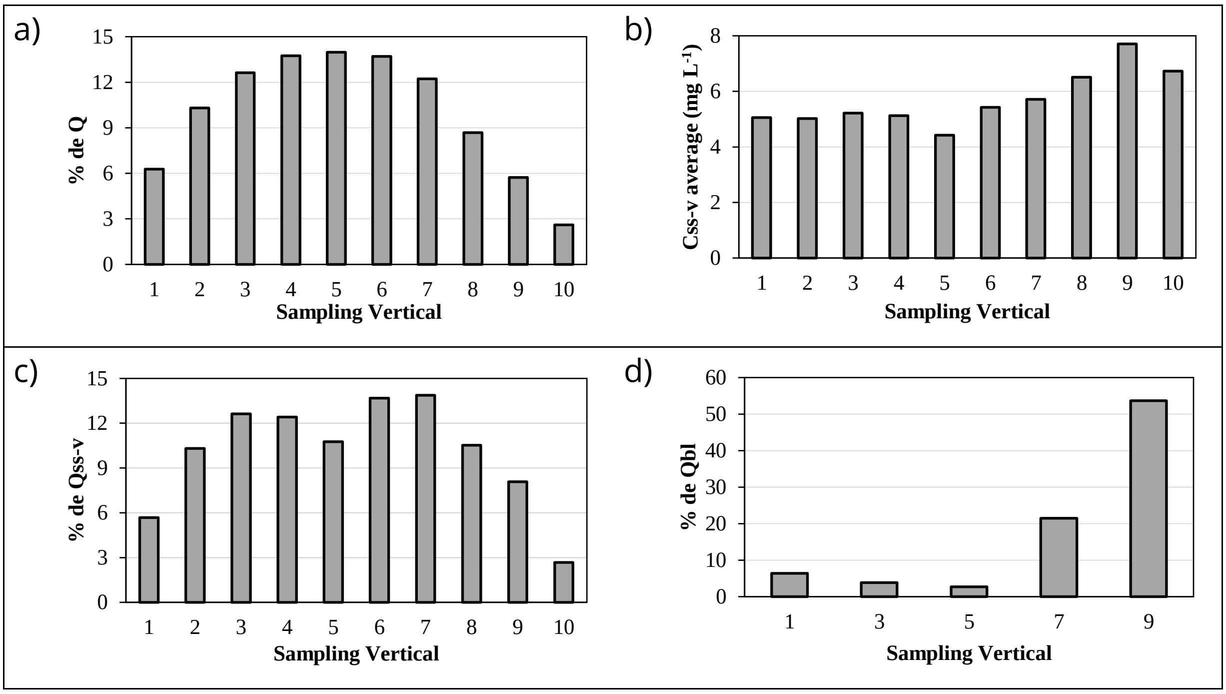
Figure 4 illustrates the average hydrosedimentometric profiles outlined from the flow, sediment concentration, solid discharge in suspension and bed load discharge from each vertical.

The flow distribution (Figure 4a) followed the geometry of the cross section (Figure 2), with higher flows in the central portions of the channel (deeper) and smaller flows close to the margins (less deep), with vertical 10 being the smallest contributor, below 3%, and vertical 5 the largest, around 14%. The average concentration in the verticals (Figure 4b) and the solid drag discharge (Figure 4d) obtained profiles with the lowest values in vertical 5 and the highest values close to the right margin, especially in vertical 9. In the solid discharge profile shown in Figure 4c, product of the flow (Figure 4a) and the average concentration in the verticals (Figure 4b), it is possible to notice the striking performance of the flow on the sediment transport.

The concentrations of suspended sediments and bed load discharges found in the right portion of the section are due to the natural silting observed from the vertical 7. According to Andrade *et al.* (2013), geomorphology and hydrodynamics are important factors in the discussion of sedimentary deposition. From such perspective, a hypothesis can be elucidated in order to justify this problem in the Rio Caiabi control section: the presence of intricacies before and after the control section which reduces the speed of flow in verticals 9 and 10 (Figure 4a), an event that, while aligned with the erosive process of the right margin, causes the decantation of the solid material.

Verticals 7 and 9 were responsible for 75% of the observed bed load discharge, which varied between 0.01 and 1.06 t d^{-1} (Table 1) and presented around 90% sand in the granulometric composition (Figure 5). The seasonal change in flow, close to 300% (Table 1), did not influence the granulometry of the collected material nor did it offer a significant correlation with the solid drag discharge (Figure 6), which, in turn, represented less than 10% of the solid discharge total.

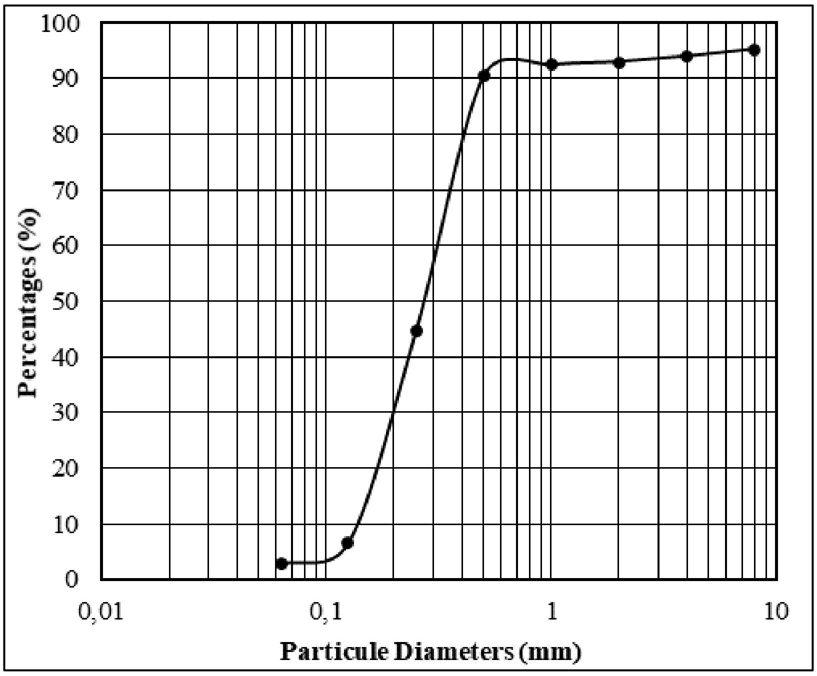
Figure 4 – Percentage average contribution, per vertical, in the flows (a), average concentration per vertical (b), solid suspended discharges (c) and bed load discharges (d), in the control section of the Caiabi river in the period from 2018 to 2020



Source: Authors (2020)

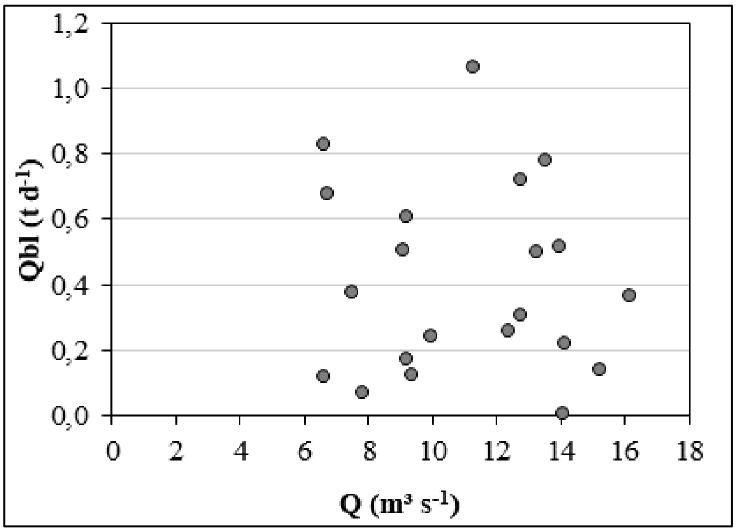
In the northern middle region of the state of Mato Grosso, studies in other microbasins on the Teles Pires River obtained background material with a similar granulometry to that of the Caiabi River (ANDRADE *et al.*, 2017; DAMAS MACHADO *et al.*, 2017; ROCHA *et al.*, 2018). Reflecting the condition of its tributaries, the bottom material collected in some points of the Teles Pires River showed values of fine sand above 95% (MACHADO *et al.*, 2017a; MACHADO *et al.*, 2017b).

Figure 5 – Particle size curve of the bottom material in the control section of the Caiabi River from 2018 to 2020



Source: Authors (2020)

Figure 6 – Relationship between flow and bed load discharge in the control section of the Caiabi River from 2018 to 2020



Source: Authors (2020)

3.2 Rating curves of solid discharge

16 rating curves were made, divided into 4 groups according to the type of sediment sampling in suspension, compound or extra, and type of solid discharge, in suspension or total (Figures 7, 8, 9 and 10). The design of confidence intervals with a 5% significance level helped to better visualize the adherence of the adjustments to the observed data.

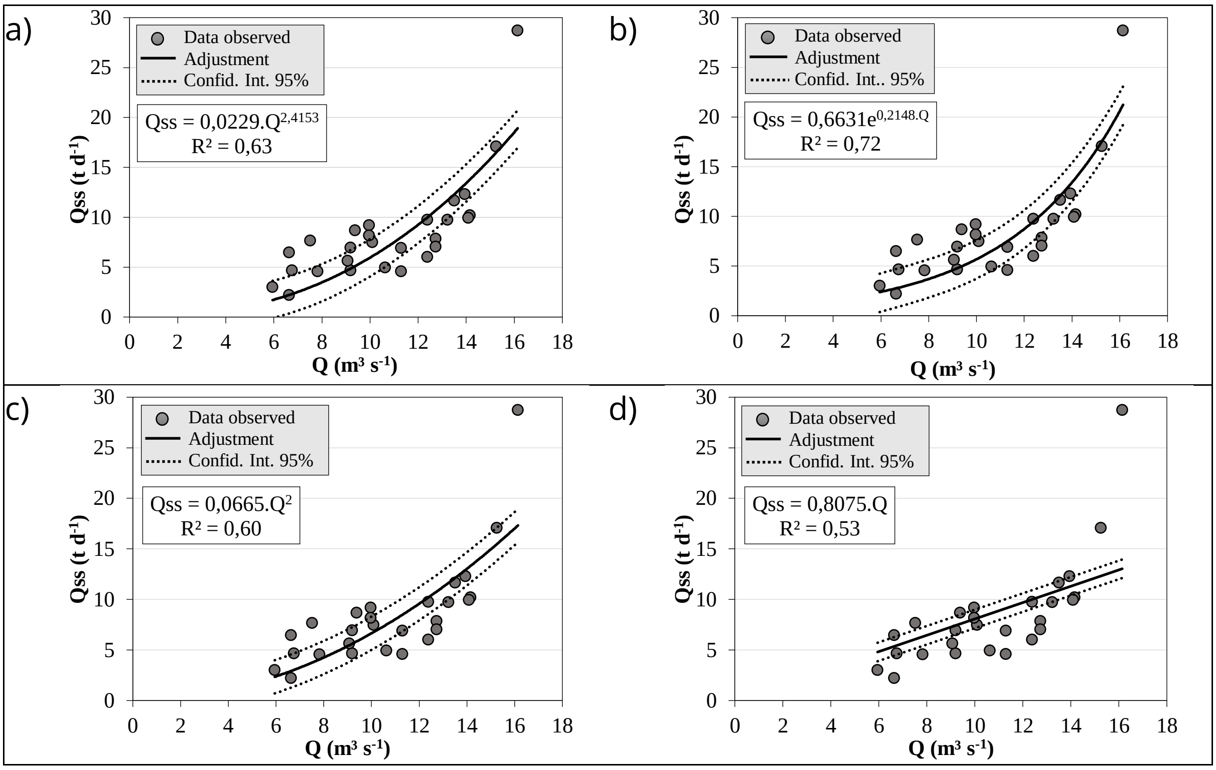
There were three different behaviors between the pairs "flow x solid discharge in suspension / total". In flows up to 10 m^3 s^{-1}, the most spread points indicated a certain fluctuation in the solid discharge during the drought and the beginning and end of the rains; in flows between 10 and 14 m^3 s^{-1}, the trend of the points indicated more correlated data during the full season; and in flows above 14 m^3 s^{-1}, the sharp increase in solid discharge calls attention to factors such as precipitation, as the data were observed in extreme events.

As for the models, the power and exponential adjustments underestimated the solid discharges at flows up to 10 m^3 s^{-1} and overestimated the solid discharges between 10 m^3 s^{-1} and 14 m^3 s^{-1}. In flows above 14 m^3 s^{-1}, the curve of the exponential adjustment pointed to estimates of solid discharges closer to those observed, while the power model had less accentuated slopes. The polynomial model was the one that best adjusted to solid discharges for flows up to 10 m^3 s^{-1}, however, it overestimated solid discharges between 10 m^3 s^{-1} and 14 m^3 s^{-1} and the solid discharges at the flows above of 14 m^3 s^{-1} were underestimated. The linear model, in general, overestimated solid discharges for flows up to 14 m^3 s^{-1} and underestimated solid discharges for flows above this value.

Although the determination coefficient (R^2) is used as an indicator of fit quality, there is no consensus on its ideal values for hydrosedimentological studies, however, many authors assess $R^2 \geq 0.60$ as satisfactory (BELLINASO *et al.*, 2007; DE GIROLAMO *et al.*, 2015; GHAFARI *et al.*, 2017; LATUF *et al.*, 2019; PEIXOTO *et al.*, 2018). According to Horowitz (2003), this statistic is quite insensitive to the estimates derived from the rating curves, thus, one must observe the dispersion measures and not only how well the curve fits the data points.

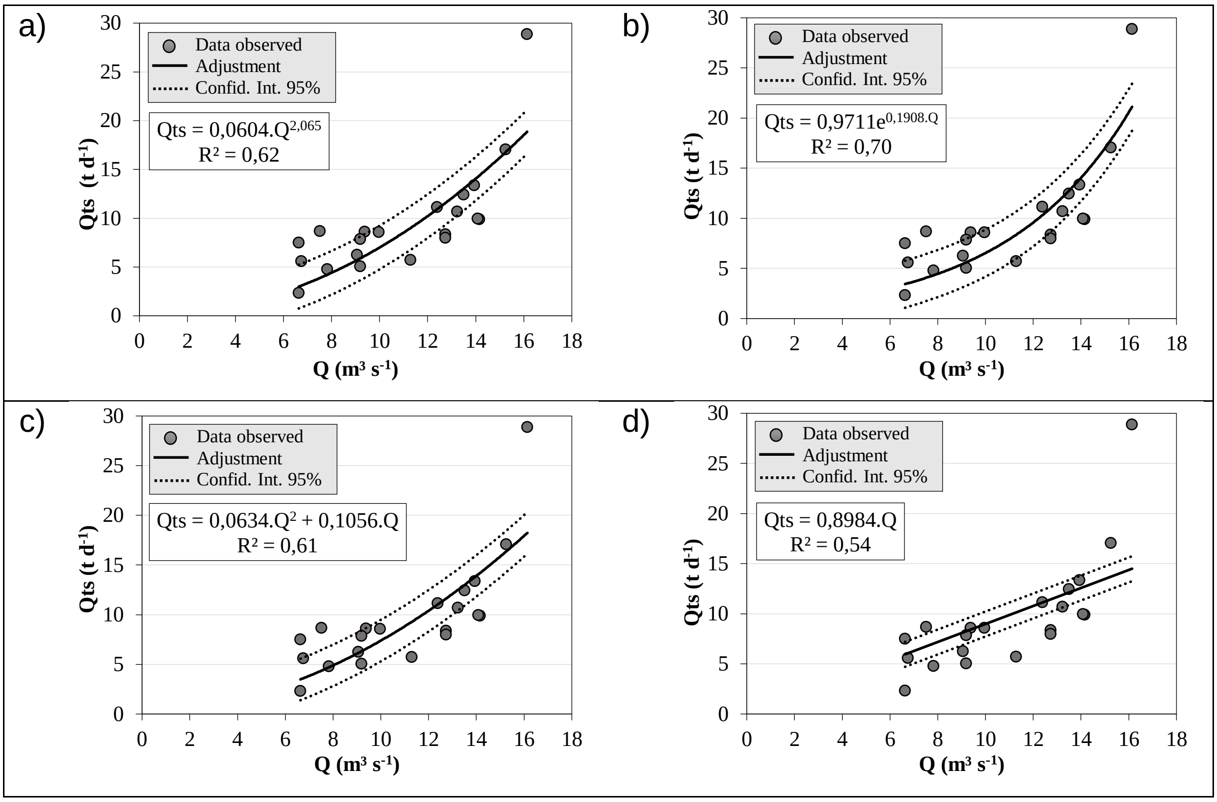
According to the statistical performance of the models presented in Table 2, for the R^2 of the adjustments between 0.47 and 0.72, the r values indicated strong correlations, the NSE indexes between indicated that the adjustments were very good, the average errors (RMSE) were less than 4 t d-1 and the majority of the mean absolute deviations (D) was less than 40%.

Figure 7 – Behavioral Patterns of power (a), exponential (b), polynomial (c) and linear (d) adjustments for the rating curves of solid discharge in suspension by composite samples



Source: Authors (2020)

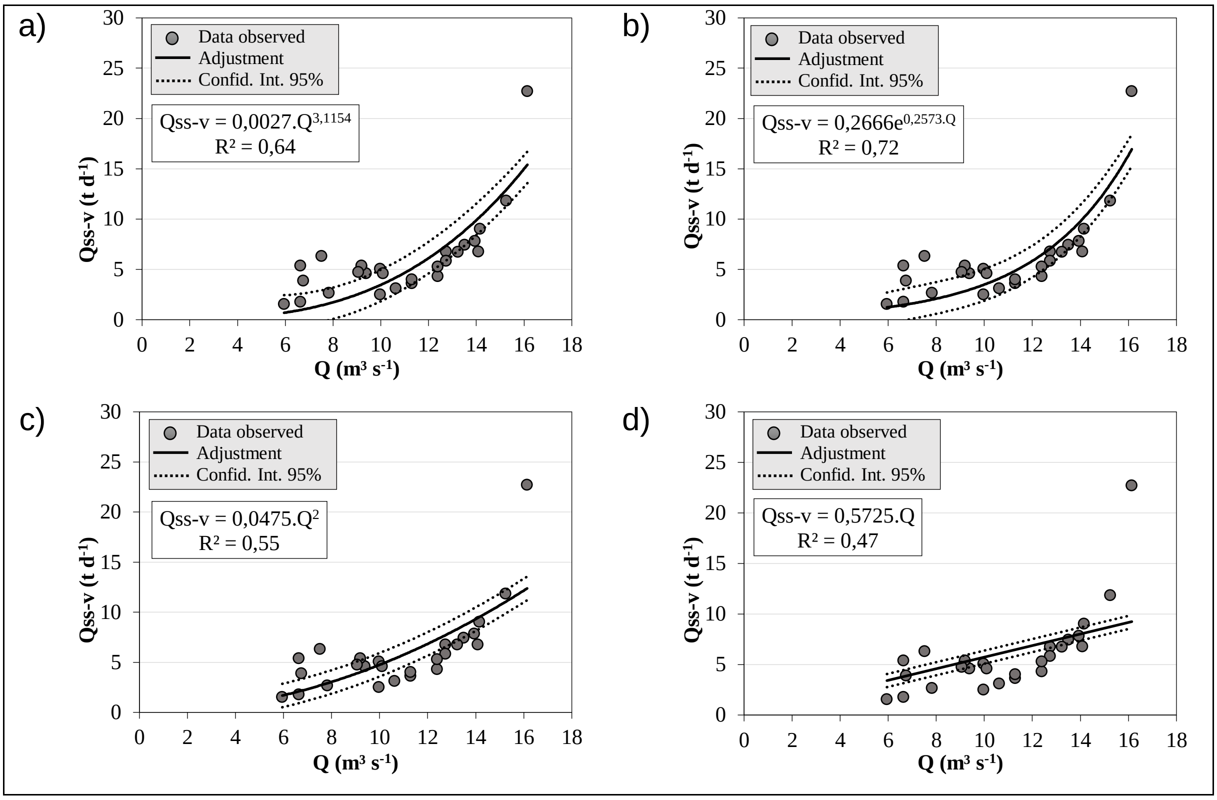
Figure 8 – Behavioral patterns of power (a), exponential (b), polynomial (c) and linear (d) adjustments for the rating curves of total solid discharge by samples of composite suspended sediments and bed load



Source: Authors (2020)

The rating curves of Q_{ss} and Q_{ts} obtained the best statistics, except for the root of the mean square errors (RMSE), which can be justified by the lesser dispersion of the points in the graphs of $Q_{(ss\text{-}v)}$ and $Q_{(ts\text{-}v)}$. The addition of the bed load discharge (Q_{bl}) to the suspended discharges (Q_{ss} and $Q_{(ss\text{-}v)}$) to compose the total solid discharges (Q_{ts} and $Q_{(ts\text{-}v)}$) improved the values of RMSE, D and NSE in all models, on the other hand, worsened the correlation coefficients (r) and determination (R^2) in the Power and Exponential models. Regarding the R^2, r, NSE and RMSE indicators, the exponential model presented the best fit, followed by the power, polynomial and linear models. For the deviations (D), the highest values were found for the power model, followed by exponential, polynomial and linear models.

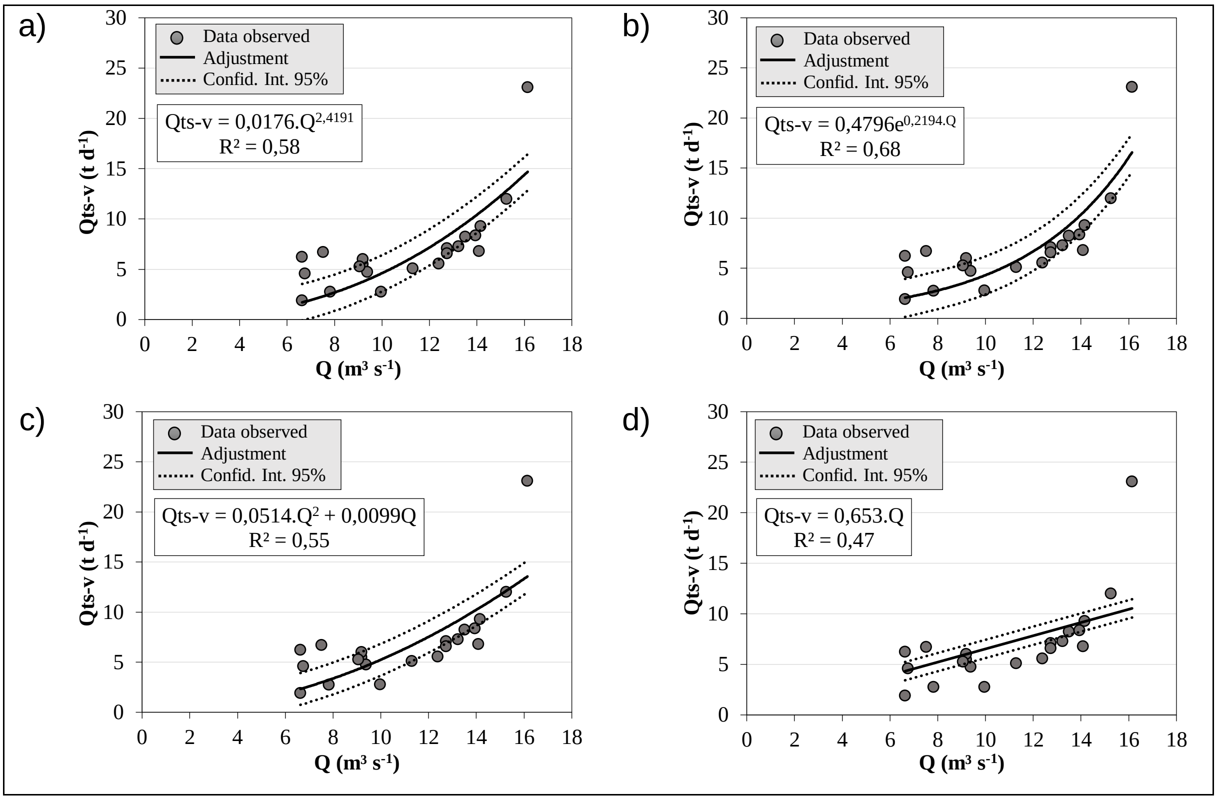
Figure 9 – Behavioral patterns of power (a), exponential (b), polynomial (c) and linear (d) adjustments for the rating curves of solid discharge suspended by samples in verticals



Source: Authors (2020)

The statistics of the rating curves of the solid discharge of the Caiabi River are in accordance with sedimentometric studies in other rivers. With data from 6 sub-basins on the Uruguay River, Bellinaso *et al.* (2007) elaborated 68 Q_{ts} rating curves using the power, polynomial and linear models, and found R^2 between 0.62 and 0.99. For the Acre River, Latuf & Amaral (2015) adjusted the rating curves of Q_{ss} using the linear, exponential, logarithmic, polynomial and power models, finding R^2 between 0.50 and 0.92, correlations (r) between 0.51 and 1.00 and NSE between -444.40 and 0.87. For the Celone River, De Girolamo *et al.* (2015) found R^2 equal to 0.61, 0.61 and 0.63 and mean absolute deviations (D) equal to 60, 60 and 58% for C_{ss} rating curves of the power, linear and polynomial grade 2 models, respectively. Moges et al. (2016) found coefficients of determination (R^2) between 0.64 and 0.89 and efficiency indices (NSE) between 0.61 and 0.83 for C_{ss} rating curves of the power model in contributing Lago basins Tana. Menezes *et al.* (2021) found R^2 between 0.79 and 0.83 in the construction of the Q_{ts} rating curve for the Sinos River.

Figure 10 – Behavioral patterns of power (a), exponential (b), polynomial (c) and linear (d) adjustments for the rating curves of total solid discharge by sediment samples suspended in verticals and bed load



Source: Authors (2020)

Table 2 – Statistical performance of the sediment rating curve models for the control section of the Caiabi River from data from the period 2018 to 2020

Rating curve	**Model**	R^2	r	NSE	$RMSE$	D
Q_{ss}	Wattage	0,63	0,79	0,90	3,14	42,43
	Exponential	0,72	0,85	0,92	2,76	35,72
	Polynomial	0,60	0,78	0,89	3,18	31,98
	Linear	0,53	0,73	0,85	3,75	26,39
Q_{ts}	Wattage	0,62	0,79	0,90	2,98	35,56
	Exponential	0,70	0,84	0,93	2,64	32,92
	Polynomial	0,61	0,78	0,91	2,98	30,55
	Linear	0,54	0,74	0,88	3,42	24,55

Continued...

Table 2 – Continuation

Rating curve	Model	R^2	r	NSE	$RMSE$	D
Q_{ss-v}	Wattage	0,64	0,80	0,87	2,52	78,89
	Exponential	0,72	0,85	0,90	2,19	53,06
	Polynomial	0,55	0,74	0,86	2,65	35,28
	Linear	0,47	0,68	0,81	3,11	29,52
Q_{ts-v}	Wattage	0,58	0,76	0,88	2,50	51,69
	Exponential	0,68	0,82	0,91	2,20	44,58
	Polynomial	0,55	0,74	0,88	2,52	38,42
	Linear	0,47	0,69	0,84	2,86	27,68

In were: **R^2**: Wattage coefficient; r: correlation coefficient; **NSE**: Nash-Sutcliffe efficiency index; **RMSE**: root of the mean squared errors in $t.d^{-1}$; e **D**: absolute mean deviations in %.

4 CONCLUSION

Statistically, the total solid discharge obtained from the combination of samples formed by suspended sediments and bed load sediments samples is the one that better represents the sediment flow in the section by showing the rating curve of the exponential model the best fit to the observed data.

Although the Caiabi River has low sediment transportation based on the hydrosedimentometric design carried out, further study of the geomorphological and hydrodynamic characteristics close to the section is suggested in order to better understand the fluvial dynamics of this water body.

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