

Original Research Article

EVALUATING OF SEDIMENT DELIVERY RATIO ON SPATIAL AND TEMPORAL VARIABILITIES IN SEMIARID WATERSHED BRAZIL

ABSTRACT

Evaluation of sediment delivery ratio is important for determining watershed sediment yield. Rates of both interrill and rill erosion were calculated under shrub and uncovered Inceptisols conditions and was not observed to the presence by ravines and gullies in the watershed of Jacu River, in a semiarid region, Brazil. Direct measurement campaigns of suspended sediment and bedload were also carried out by means of the US DH-48 for collection of suspended sediment samples and US BLH-84 used to collect samples bed load. The soil loss due to interrill erosion under uncovered conditions was equal to 8.43 t ha⁻¹ and was considered high, and the same was true for the values of rill erosion with erodibility equal to 0.0021142 kg N-1 s⁻¹ and critical shear stress (τ_c) equal to 2.34 Pa. The mean value of sediment delivery ratio of Jacu watershed was equal to 0.165 and ranged from 0.29 in the year 2008 to 0.026 in 2010. This variation was associated with the natural variability of semiarid environment, indicating the necessity of assessment for a longer period to deepen our knowledge of sediment delivery ratio of the Jacu semiarid watershed.

Keywords: watershed sediment yield, semiarid region, sediment delivery ratio, erosion,

1. INTRODUCTION

In semiarid climatic zones, hydrological processes are variable both in time and in space. Suspended sediment load is generally high and reaches a maximum value at the beginning of flood season and after dry periods [1]. Therefore, only some of the eroded soil is routed to the basin outlet.

The ratio between the watershed sediment yield at the basin outlet and soil erosion over the basin is called the sediment delivery ratio (SDR) [2]. The values of SDR for an area have been found to be affected by catchment sediment sources, transport system, texture of eroded material, urbanization, and land cover [3] and [4]. However, sediment yield is usually not available as a direct measurement for many watersheds but is estimated by using SDR, defined as the fraction of gross erosion that is transported from a given watershed in a given time interval.

Prediction of SDR is important for sediment control needed for sustainable development of natural resources and environmental protection [5]. Estimating the amount of soil loss from watersheds and sediment yield for watershed is the first step [6] for computing SDR. High sediment yields are produced in semiarid environments because of the interaction between erosive energy and vegetation density, even if climatic seasonality, relief, watershed lithology and the extent of human activity combine to influence the erosion pattern.

Estimation of sediment transport during precipitation events is necessary for the calculation of long-term sediment yields from basins, as one single event may not represent the transport of several 'normal' years [7]. The equation due to Lane et al. [8] is used to describe erosion in interrill. The Dubois channel scour equation [9] has been modified for rill erosion [10]. In the WEPP model [8] one considers the effect of runoff and water infiltration rate of breakdown. Sediment Delivery Ratio (SDR, equations [3]) have been used to estimate catchment-scale sediment yield,

The WEPP, used in the water erosion prediction Project, is one of the most promising models owing to its theoretical basis and mathematical formalization of the physical processes of soil erosion [11]. Sediment mobilized by interrill and rill erosion may be deposited by a variety of mechanisms prior to reaching stream channels [12]. The objectives of this study therefore were to predict sediment

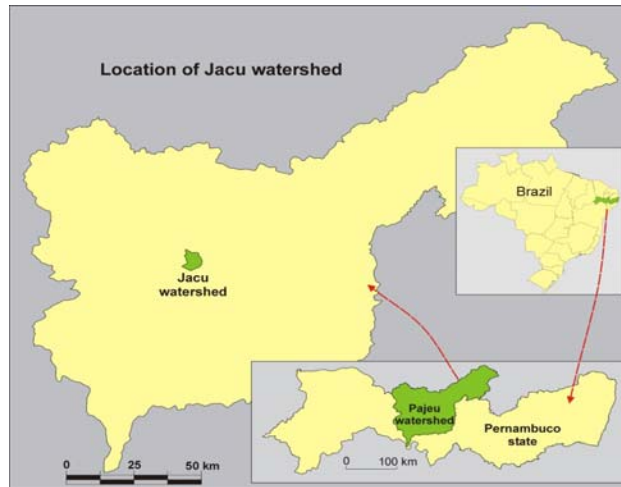
Comment [UdW1]: x. Insert: US DH-48 for collection of suspended sediment samples and US BLH-84 used to collect samples bed load

Comment [V2]: a. Exclude: Was not observed to the presence by ravines and gullies in the watershed of Jacu River.
This sentence is not in the right place. The right place for this sentence is in methodology and not in article introduction. Apologies

43 delivery ratio and estimate sediment transport during the events of hydraulic erosion on the semiarid
44 Jacu watershed located in Northeastern Pernambuco, Brazil.

45 2. MATERIAL AND METHODS

46
47
48 The study area is located in the Jacu watershed limited between the coordinates latitude -8°07'55" S
49 and -8°09'07" S and longitude -38°23'20" W and -38°24'14" W, Fig.1 in a semiarid environment
50 between the cities of Serra Talhada and Floresta in the state of Pernambuco, Brazil. The climate is
51 classified as hot and dry, BWh according to the Köppen type climate classification. The most common
52 soil types found in the watershed include the Entisol Udorthent and Fluvent raised by [13] and
53 Inceptisol Ochrept [14].
54



55
56
57 **Figure 1. Location of experimental area Jacu watershed in Brazil.**
58

59 To measure stream flow rate, was installed in the control section of Jacu River the sensor for measure
60 flow with data logger SL2000MIM for the monitoring station 23 campaigns were performed for direct
61 measurement of hydraulic characteristics of speed and height of runoff in Jacu river. The average
62 runoff velocity (m s^{-1}) was determined by integration of the profile through the use of a type of current
63 meter.
64

65 The suspended sediment yield (Y) was calculated by solid discharge measured continuously in
66 accordance with the procedure of the United States Geological Survey [15], with the use of one of
67 sampler's sediments (US BLH-84) with the collections of bottom sediment. The method of Equal
68 Width Increment (EWI) was used for sampling suspended sediment and in the bottom sediment.
69

70 Samples were collected by lowering and raising a sampler through the water column at the center of
71 each increment utilizing a US DH-48 for collection of suspended sediment sampler at equal width
72 intervals across the stream. The transit rate used for make possible the collection of representative
73 samples was equal in both directions to seeking smaller probability to error [16].
74

75
76 After collecting the suspended sediment samples were taken to the laboratory where they was dried
77 at 60 ° C for the determination of the concentration values of sediment, which was obtained by
78 evaporation method indicated by United States Geological Survey [15]. The suspended solid
79 discharge (QSS) was determined by summing the product of suspended sediment concentration
80 (CSS) and respective liquid discharge (Q) of each vertical [17].
81

82
$$Q_{SS} \equiv \sum (C_{SS} Q_i) 0,0864 \dots \dots \dots (1)$$

83
84

In this research the solid bedload discharge was determined the following formula are applied [18].

Comment [UdW3]: z. Insert: The study area is located in the Jacu watershed limited between the coordinates latitude -8°07'55" S and -8°09'07" S and longitude -38°23'20" W and -38°24'14" W, Fig.1 in a semiarid environment between the cities of Serra Talhada and Floresta in the state of Pernambuco, Brazil

Comment [UdW4]: Insert: (US BLH-84) with the collections of bottom sediment

Comment [UdW5]: Insert: a US DH-48 for collection of suspended sediment

Comment [V6]: f. this is correct. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

Comment [UdW7]: b. this is correct.

Comment [V8]: g. Exclude: , following the expression Horowitz. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

Comment [V9]: h. this is correct. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

$$Y_{SS} = \frac{Q_{SS} \times X}{A} \dots\dots\dots (2)$$

Gross erosion is the sum of soil loss from rill and interrill erosion, ephemeral gullies and classical gully reported in tons/acre/year. The study used field observation and not found the presence by ravines and gullies in the watershed of Jacu River.

Comment [UdW10]: c. this is correct.

For erosion research was used rainfall simulator with 80 - 150 Veejet nozzles, having an impact energy of 2750 kJ (ha cm) [19] in interrill simulators and reproduce a distribution of droplet size and levels of kinetic energy near the natural rainfall. The average rainfall intensity 90mm⁻¹ was measured using a set of 10 pluviometers placed at random within and adjacent to the working area of experimental plots.

Comment [UdW11]: d. this is correct.

The plots consisted of an area of 2 m² (1 m wide and 2 m long), with the longer dimension in the direction of slope, and were bounded by galvanized sheet metal 30 cm, driven into the ground at 20 cm depth.

Three treatments replicated three times: soil with semi - shrubby caatinga vegetation; soil with herbaceous residue in decomposition and soil uncovered; representing three likely conditions typical of interrill erosion in watershed were employed. The experimental design was completely randomized in that treatments were assigned to units completely by chance in three replicates of each treatment.

Statistical analysis was performed using SAS version 8.0 [20], using Tukey's difference between the mean efficiencies at a 5 % level of significance and Curve Expert for comparing regression models of the best fit equation.

The pre-formed rill was delimited laterally by placing zinc metal sheets buried in the soil, subjected to erosion tests that were applied with 04 (four) flow levels randomly and for 20 minutes [21]. At the upper end, rill energy dissipaters were buried in the form of round plastic containers, so that the upper edge of the container was at the level of soil surface.

These containers had hoses for conducting water in order to reach the rill by overflowing of containers. The collected volumes of samples of liquid and solid discharges were measured in a test tube and placed in plastic containers 1L for subsequent determination of sediment concentration.

Flow velocity was measured visually with a dye tracing technique (potassium permanganate) using a stopwatch to record the time required for the dye to travel a given distance [22],[23] and [24] was determined by multiplying the values obtained during the testing of surface velocity by a correction factor $\alpha = 0.6$ [21], [25] and [26].

Comment [V12]: i. Exclude: which has been used by Cantalice, Braida & Cassol and Slattery & Bryan. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

The slope of plots on rill was determined prior to testing, with the aid of a level, obtaining the height difference between two points of known distance, the result being expressed in m m⁻¹. In order to calculate the hydraulic radius of a preformed rill (A/P), the cross sectional area (A) of the rill and the wetted perimeter (P) was determined using perfilometer.

The perimeter of the rill was measured utilizing a curvimeter analog. The hydraulic radius that was used to calculate the shear stress of flow. From the mass of dry soil and the duration of sampling, the rates of breakdown of soil in the rill [21].

Assuming that the erosion of rill with the addition of flow, sediment load was much greater than the transport capacity, the capacity of breakdown of flow in the rill was used for determining the momentary rate of breakdown of flow [27].

Comment [V13]: j. Exclude: , expressed by Elliot et al. . In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

Thus, soil erodibility in sulcus was determined by linear regression analysis between the average values of shear stress and the breakdown of soil obtained for each flow, as in the prediction model WEPP [28]. The soil losses were calculated from the data of instantaneous sediment concentration of runoff and the liquid discharge [29].

Comment [V14]: k. Exclude: according Cantalice. . In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

Experimental evaluation was done for increasing levels of flow: 1) Flow 14.95 L min⁻¹; 2) Flow 28.70 L min⁻¹; 3) Flow 39.85 L min⁻¹; and 4) Flow 67.405 L min⁻¹ in four replications. Statistical analysis was

performed using SAS version 8.0 [20], using Tukey's difference between the mean efficiencies at a 5 % level of significance. Curve Expert was used for comparing regression of the best-fit equation.

3. RESULTS AND DISCUSSION

Vegetation reduced flow velocity by providing a rough surface that slowed runoff velocity and promoted infiltration [30], achieved the same effect of retardation of flow through the dossal of caatinga. These results showed the importance of the caatinga vegetation cover to protect the soil of the semiarid watershed. From Table 1 it was observed that the values of hydraulic roughness for the conditions of vegetation were higher than in the uncovered soil, justifying the reduction in speed and flow and showing that the elements of dossel of caatinga vegetation and residues in contact with soil gave rise to physical and hydraulic resistance to runoff.

The flow Reynolds number and Froude number characterized a laminar and subcritical flow regime, as indicated by the values of $Re < 500$ and $Fr < 1$, respectively, typical of interrill erosion flow conditions [31], [32], [33] and [34].

Table 1. Hydraulic characteristics of runoff generated by simulated rainfall under the conditions studied in the watershed of Jacu River.

Variables	Treatments		
	T1	T2	T3
$q(m^2s^{-1})$	1.4×10^{-5} B	1.9×10^{-5} A	2.9×10^{-5} A
$h(mm)$	0.68 ns	1.115 ns	0.68 ns
$V(m s^{-1})$	0.017 A	0.015 A	0.043 B
Re(adm)	17.46 ns	22.36 ns	34.58 ns
Fr(adm)	0.2391 A	0.1466 B	0.5368 A
$\log f(adm)$	1.0643 A	1.3940 A	0.2273 B

Means followed by capital letters in the same row do not differ from each other, 5% level of significance, in Tukey test. q = liquid discharge; h = blade height of runoff; V = runoff velocity; Re = Reynolds number; Fr = Froude number; $\log f$ = hydraulic roughness (Darcy Weisbach coefficient); Treatments: T1: caatinga vegetation semi-shrub; T2: litter; T3: undercoverd soil.

The caatinga vegetation and litter on soil developed a high degree of contact that increased opportunities for infiltration slowing down, giving more time for infiltration. This was confirmed by the roughness elevation (f) and infiltration rates. Water was stored in the foliage, giving more time for infiltration, so reducing the volume of runoff [35], [36], and [30] obtained similar relationships.

Table 2. Infiltration rates, runoff coefficient (C), soil detachment rates in interrill (Di), and soil loss (PS) obtained under diferents treatments studied.

Variables	Treatments		
	T1	T2	T3
Infiltration rates($mm h^{-1}$)	38.41 A	41.84 A	9.29 B
C(adm)	0.36 B	0.55 A	0.89 A
$D_i(Kg m^{-2} s^{-1})$	8×10^{-5} B	4×10^{-5} B	3.2×10^{-4} B
PS($t ha^{-1}$)	1.22 B	0.74 B	8.43 A

*Means followed by the same capital letters on the lines do not differ significantly by the Tukey test ($p < 0.05$). Treatments: T1: Caatinga semi-shorubby; T2: Litter; T3: uncovered soil.

The soil loss for the Inceptisol uncovered area $8.43 t ha^{-1}$ was much higher than that observed by the caatinga vegetation semi-shrubby conditions and soil covered by litter in table 2, constituting very high losses for young soils with poorly developed profiles, and caatinga deciduous vegetation included total loss of leaves during the dry season. Results showed that soil losses were considered very low as proposed by U.S. Department of Agriculture, FAO [37] in [38]; established in the 1950s soil-loss tolerance values.

In rill erosion the values of Reynolds numbers (Table 3) above 2500 for the larger values of flows applied between 28.7 and $67.4 L min^{-1}$, characterized the regime of runoff as turbulent flow, and the lower flow of $14.95 L min^{-1}$ generated a regime transitional runoff [39], [40], [21],[41] and [42]. The Froude number for all flows was below 1.

Comment [UdW15]: r.Exclude: Table 1. Hydraulic characteristics of runoff generated by simulated rainfall under conditions of caatinga vegetation semi-shrub, soil covered by litter and undercoverd soil in the watershed of Jacu River. In atention 7. Titles of the tables shloud be reduced. Insert: **Table 1. Hydraulic characteristics of runoff generated by simulated rainfall under the conditions studied in the watershed of Jacu River.**

Comment [UdW16]:

Comment [UdW17]: l.y. Insert: Treatments in table 1 (for best visible or clear)

Comment [UdW18]: s. Exclude: Table 1. Hydraulic characteristics of runoff generated by simulated rainfall under conditions of caatinga vegetation semi-shrub, soil covered by litter and undercoverd soil in the watershed of Jacu River.

Insert: **Table 2. Infiltration rates, runoff coefficient (C), soil detachment rates in interrill (Di), and soil loss (PS) obtained under diferents tratments studied.**

Comment [UdW19]: Insert: Insert: Treatments in table 2 (for best visible or clear)

The regime observed was tranquil or subcritical flow. The average gradient slope in rill plots and roughness measured by the Darcy-Weisbach coefficient (Table 3) showed no statistically significant differences.

Table 3. Different discharge rates applied to the upper end of rills preformed for determining soil erodibility parameters.

Variables	Different discharge rates (L min ⁻¹)			
	14.95	28.70	39.85	67.40
Q(L min ⁻¹)	12.465 B	26.135 B	36.554 A	58.723 A
Vm(m s ⁻¹)	0.182 B	0.238 A	0.280 A	0.310 A
S(mm ⁻¹)	0.049	0.051	0,052	0,052
Re(adm)	1,920.21 B	5,252.53 A	5,132.24 A	4,522.30 A
Fr(adm)	0.647	0.590	0,750	0,829
log f(adm)	1.396	1.418	1,166	1,087

*Means followed by the same capital letters on the lines do not differ significantly by the Tukey test ($p < 0.05$).
Q= liquid discharge; Vm= mean flow velocity; S= slope in rill plots preformed; Re= Reynolds number; Fr= Froude number; log f = hydraulic roughness (Darcy Weisbach coefficient).

The shear stress obtained differed significantly when low flow was compared with higher flows (Table 4) depending on the variation of hydraulic radius causing different breakdown rates of soil due to larger flows applied (39,85 and 67,40 L min⁻¹). Similarly, soil losses (PS) were already higher from the second level of flux (6.601 and 24.889 t ha⁻¹) high values were considered for soils normally very shallow and with extreme variability spatial and temporal characteristic of rainfall in semiarid, soil losses associated with man's intervention in land and water.

Table 4. Erosion parameters in rills preformed under simulated rainfall.

Erodibility parameters	Different discharge rates (L min ⁻¹)			
	14.95	28.70	39.85	67.40
τ (Pa)	4.376 B	5.128 A	6.285 A	13.079 A
Dr(Kg m ⁻² s ⁻¹)	0.0028 B	0.0053 B	0.0096 A	0.0246A
Ps (t ha ⁻¹)	3.150 B	6.601 A	13.576 A	24.889 A

*Means followed by the same capital letters on the lines do not differ significantly by the Tukey test ($p < 0.05$).

The value of rill erodibility (Kr) was obtained by coefficient b or slope of the regression line 0.0021142 kg N⁻¹ s⁻¹ [43], [44], as described in [40] and the intercept with the horizontal axis was the critical shear τ_c 2.34 Pa (Fig. 2).

The rill erodibility values obtained were higher than those determined by Lafayette et al. [45] for Latosols (Oxisols) 0.0016 kg N⁻¹ s⁻¹, [41] and [25] for two Argisols of 0,012 KgN⁻¹s⁻¹ and 0.0104 kg N⁻¹ s⁻¹, respectively. This higher value was justified by the fact that this Inceptisol in semiarid regions is young soil, generally shallow and weakly developed soil, than the Latosols (oxisols) and Ultisols that are commonly found.

The value of critical shear stress (τ_c) of 2.34 was also lower than that determined by various Argisols [41], [46] and [21].

Comment [UdW20]: w. Exclude: The shear stress obtained differed significantly when low flow was compared with higher flows (Table 4) depending on the variation of hydraulic radius causing different breakdown rates of soil due to larger flows applied (39,85 and 67,40 L min⁻¹). Similarly, soil losses (PS) were already higher from the second level of flux (6.601 and 24.889 t ha⁻¹) high values were considered for soils normally very shallow and placed extreme environmental variability.

Insert: The shear stress obtained differed significantly when low flow was compared with higher flows (Table 4) depending on the variation of hydraulic radius causing different breakdown rates of soil due to larger flows applied (39,85 and 67,40 L min⁻¹). Similarly, soil losses (PS) were already higher from the second level of flux (6.601 and 24.889 t ha⁻¹) high values were considered for soils normally very shallow and with extreme variability spatial and temporal characteristic of rainfall in semiarid, soil losses associated with man's intervention in land and water.

Comment [V21]: n.Exclude: Knapen & Poesen. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

Comment [V22]: q. Exclude: Schäfer et al. and Braida & Cassol. In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

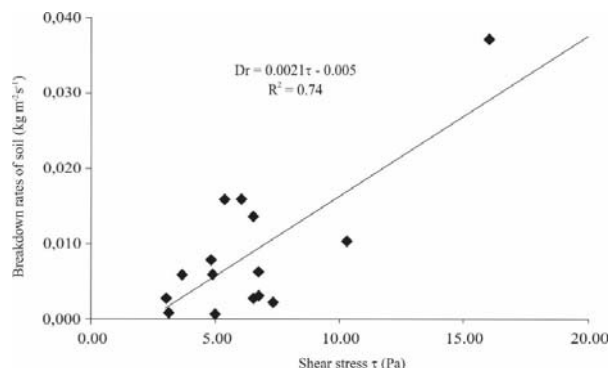


Figure 2. Rill erodibility (K_r) and critical shear stress (τ_c) obtained by the linear regression generated by leading to increasing runoff.

The sediment yield (Y_t) ranged from 0.45 to 1.72 $t\ y^{-1}$ and was considered low for 4 years (Table 5). The respective amounts of suspended sediment concentration (SSC) ranging from 874 to 376 $mg\ L^{-1}$ was considered high for a small watershed and for low values of liquid discharged.

Table 5. Values of average discharged liquid (Q) discharge suspended solid [Qss] and bottom discharge [Qsf], Sediment yield determined for the period 2008 to 2011.

Year	Q $m^3 s^{-1}$	SSC $mg\ L^{-1}$	X days	Qss $t\ day^{-1}$	Qsf	Yss $t\ ha^{-1}$	Ysf $year^{-1}$	Yt	Yt $t\ year^{-1}$
2008	0.12	376.74	76	3.80	0.42	1.38	0.35	1.72	361.66
2009	0.06	428.41	148	2.22	-	1.57	-	1.57	329.27
2010	0.01	874.53	45	0.66	0.05	0.14	0.01	0.15	31.98
2011	0.02	473.00	105	0.87	0.04	0.43	0.02	0.45	94.71

SSC: suspended sediment concentration; Qss: discharge suspended solid; Qsf: bottom discharge solid; Yss: Suspended sediment production; Ysf: Bottom sediment production; Yt: Total sediment production.

The Jacu watershed showed the average sediment concentration of 874 $mg\ L^{-1}$ for a period only 45 days of flow in 2010. The rainfall distribution in simple peak events [47] was unimodal or bimodal with interannual variation characterizing the pattern of low rainfall in arid and semiarid regions concentrated in a few months of the year and poorly distributed in the space and the time. The production of sediments was considered low by the standards adopted by the World Meteorological Organization [48] for the transport of sediment limited by climate in intermittent waterways.

The sediment delivery ratio (Table 6) values from 2008 to 2011 were obtained from the total sediment production (Y) in Table 5 and the gross erosion values (E) were obtained across sum the interrill erosion in Table 2 and rill erosion in Table 4. The interrill erosion value used was weighted by the area from the watershed use map and rill erosion was obtained from the flow application of 14.95 $Lmin^{-1}$ that may occur in this watershed for a high return period (100 years) [49].

Table 6. SDR – Sediment delivery ratio measured for period 2008 to 2011.

Year	Sediment delivery ratio* (SDR)
2008	0.291
2009	0.265
2010	0.026
2011	0.076
Average	0.165

* Adimensional

The quantitative fraction all sediment broken down and transported, but which in reality came to be transported out of the watershed (SDR) varied from 0.29 in the year 2008 to 0.03 in 2010. During this period the 2010 year presented the most irregular rainfall distribution, with a low total annual value of 370.55 mm, occurring the most rainfall on 30/10/2010 with 47 mm.

Comment [UdW23]: t. Exclude: Figure 2. Rill erodibility (K_r) and critical shear stress (τ_c) obtained by the regression line of the soil detachment rates (Dr) with the respective shear stress generated by leading to increasing runoff.

Insert: Figure 2. Rill erodibility (K_r) and critical shear stress (τ_c) obtained by the linear regression generated by leading to increasing runoff.

Comment [UdW24]: Insert: low rainfall in arid and semiarid regions concentrated in a few months of the year and poorly distributed in the space and the time

Comment [UdW25]: 1.Insert: 10. Some of the properties that accounted for the variabilities should be properly presented in the text prior to conclusion (273-276).

Comment [UdW26]: Insert: and the gross erosion values (E) were obtained across sum the interrill erosion in Table 2 and rill erosion in Table 4

Comment [V27]: o. Exclude: according to Molinier et al. . In atencion 3. Expunge all the names from the references in the text to maintain journal referencing style.

This unevenness of the rainfall and flow values in semiarid environment as well observed in the values of (SDR) rain results from the convective cells formed from the mass general circulation of the atmosphere, short, small diameter and limited scope, 10 – 14 km [47] giving the rains to arid and semiarid high spatial and temporal variability, and still interannual variability rising with aridity.

That values of the magnitude of the SDR tends to increase with increase in area being the maximum 30% or 0.3 to watershed 0.5 to 5.2 km² and ranging from 0.1 to 0.38 [3]. In this research were presented estimated values of SDR calculated for an empirical relationship found in the literature equation [9] showed in Table 7.

Table 7. Sediment delivery ratio (SDR) estimated by the equations from [9], [50] and [51].

Equação	Taxa de Entrega de Sedimentos* (SDR)
Vanoni (1975)	0.409
Williams & Berndt (1972)	0.763
NRCS (1979)	0.521

*: Adimensional

4. CONCLUSION

The sediment yield values obtained for Jacu watershed were low, because it is a small watershed, with average low slope and sediment transport limited by the semiarid climate. The soil losses by interrill erosion in the uncovered soil of 8.43 t ha⁻¹ were high, as well as the rill erosion with rill erodibility of 0.0021142 kg N⁻¹ s⁻¹ and critical shear stress τ_c of 2.34 Pa. The average value of sediment delivery ratio (SDR) of Jacu watershed was 0.165 with variation of 0.29 for year 2008 to 0.026 in 2010. The large annual variability in the sediment delivery ratio is associated with relief and slope characteristics, drainage pattern, vegetation, land use, texture, and structure of soil needing a longer period of years of assessment to better knowledge of the sediment delivery rate of the Jacu semiarid watershed. The bottom sediments are formed by medium sand particles with diameters ranging from 0.15 to 0.60 mm, uniform and well – graded.

References

1. Bisantino T, Gentile F, Liuzzi G. Continuous Monitoring of suspended sediment load in Semiarid Environmental.2011; In: SEDIMENT TRANSPORT, p.334: 295-312.
2. Lee GS, Lee KH. Determining the sediment delivery ratio using the sediment-rating curve and a geographic information system–embedded soil erosion model on a basin scale. J. Hydrol. 2010;15 (10), 834–843.
3. Walling DE. The sediment delivery problem. Journal of Hydrology 65. 1983; 209:237.
4. Subramanian V. 1996. The sediment load of Indian rivers – update. Erosion and sediment yield: global and regional perspectives. In: Proceedings of the Exeter Symposium. 1996; IAHS, 236, pp. 183–189.
5. Ouyang D, Bartholic J. 2014. Predicting sediment delivery ratio in Saginaw Bay watershed. Institute of water research, Michigan State University.2014.
6. Lee S, Kang S. Estimating the GIS-based soil loss and sediment delivery ratio to the sea for four major basins in South Korea. Water Science & Technology. DOI: 10.2166/wst.2013;194.
7. Wolman MG, Gerson R. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surf. Processes, 3. 1978; 189-208.
8. Lane LJ, Foster GR, Nicks, AD. Use of fundamental erosion mechanics in erosion prediction. ASAE. 1987; Paper No 87-2540.
9. Vanoni VA. Sedimentation Engineering: American Society of Civil Engineers, Manuals and Reports on Engineering Practice, no. 54. 1975; 745 p.
10. Meyer LD. Mechanics of soil erosion by rainfall and runoff as influenced by slope length, slope steepness, and particle size. Ph.D. thesis, Purdue University. 1964.
11. Bulygin SYu, Nearing MA, Achasov AB. Parameters of Interrill Erodibility in the WEPP Model. Erosion Soil Science.2002; Vol.35, No. 11, pp. 1237 – 1242. Translated from Pochvovedenie, No.1, pp. 1397 – 14.03. Russia.
12. Blackburn WH, Thurow TL, Taylor C. Soil erosion on rangeland.1986; p. 31- 39. In: Proc. Use of Cover, Soils and Weather Data in Range. Monitor. Symp. Soc. for Range Manage. Denver, CO. USA. Brazil. In First National Report for the Convention on Biological Diversity. Chapter 1. Brazil. Available: <http://216.95.224.234/natrep/Brazil/Brazil.html>.

Comment [UdW28]: Insert: The quantitative fraction all sediment broken down and transported, but which in reality came to be transported out of the watershed (SDR) varied from 0.29 in the year 2008 to 0.03 in 2010. During this period the 2010 year presented the most irregular rainfall distribution, with a low total annual value of 370.55 mm, occurring the most rainfall on 30/10/2010 with 47 mm. This unevenness of the rainfall and flow values in semiarid environment as well observed in the values of (SDR) rain results from the convective cells formed from the mass general circulation of the atmosphere, short, small diameter and limited scope, 10 – 14 km [47] giving the rains to arid and semiarid high spatial and temporal variability, and still interannual variability rising with aridity. That values of the magnitude of the SDR tends to increase with increase in area being the maximum 30% or 0.3 to watershed 0.5 to 5.2 km² and ranging from 0.1 to 0.38 [3]. In this research are presented estimated values of SDR calculated for a empirical relationship found in the literature equation [9] showed in Table 7.

- 309 13. Melo RO. Caracterização da Produção de Sedimentos de uma Microbacia no Semiárido
310 Pernambuco. Federal Rural University of Pernambuco, 2008. Brazil.
- 311 14. Embrapa – National Soil Research Center. Brazilian system of soil classification. 2th ed. 2006.
312 Brazil.
- 313 15. Usgs – United States Geological Survey. Techniques of Water Resources Investigations.
314 Washington, 1973.
- 315 16. Edwards TK, Glysson GD. Field Methods for Measurement of Fluvial Sediment. In: Techniques of
316 Water-Resources Investigations of the U.S. Geological Survey (USGS). Reston, Virginia. 1999.
- 317 17. Horowitz AJ. An evaluation of sediment rating curves for estimating suspended sediment
318 concentrations for subsequent flux calculations. Hydrol. Process. 2003. v.17, 3387-3409.
- 319 18. Gray JR. Sediment data collection techniques. U.S. Geological Survey Training Course. Castle
320 Rock and Vancouver, WA. 2005. CD-ROM.
- 321 19. Meyer LD, Harmon WC. Multiple intensity rainfall simulator for erosion research on row side
322 slopes. Transactions of the ASAE, St Joseph. 1979; v22, p. 100 – 103.
- 323 20. Sas Institute Inc., Cary, NC: SAS Institute Inc. SAS Online Doc. 1999; Version 8.
- 324 21. Cantalice JRB, Cassol EA, Reichert JM, Borges ALO. Hydraulic runoff and sediment transport in
325 rill in frank-clay-sandy soil. Journal Brazilian of Soil Science. 2005; 29: 597-607. Brazil.
- 326 22. Nearing MA, Norton LD, Bulgakov DA, Larionov GA, West LT, Dontsova KM. Hydraulics and
327 erosion in eroding rills. Water Resources Research. 1997; 33(4), 865 – 876.
- 328 23. Nearing MA, Bradford JM, Parker SC. Detachment of soil by Shallow surface flow. Soil Sci. Soc.
329 Am.J. 1991; (In Press).
- 330 24. Mc Isaac GF, Mitchell JK, Hummel JW, Elliot WJ. An evaluation of unit stream power theory for
331 estimating soil detachment and sediment discharge from tilled soils. Transactions of the
332 ASAE. 1992; 35: 535-544.
- 333 25. Braid JA, Cassol, EA. Erodibility in interrill and rill of a dark red Podzolic sandy loam. Journal of
334 Soil Science. 1996 v. 20, n. 1, p. 127-134.
- 335 26. Slaterry MC, Bryan RB. Hydraulic conditions for rill incision under simulated rainfall: A laboratory
336 experiment. Earth Surf. 1992; 17: 127-146.
- 337 27. Elliot WJ, Lafen JM, Kohl KD. Effect of soil properties on soil erodibility. 1989; Pap no 89-2150.
- 338 28. Flanagan DC, Ascough, JC, Nicks AD, Nearing MA, Lafen JM. Overview of the WEPP erosion
339 prediction model, technical documentation. National Soil Erosion Research Laboratory; USDA.
340 1995.
- 341 29. Cantalice JRB. Runoff and erosion in rills and interrills in different soil surface conditions. Federal
342 University of Rio Grande do Sul. 2002; 141p. Brazil.
- 343 30. Freitas ADS, Sampaio EVSB. Biological nitrogen fixation in tree legumes in Paraíba and
344 Pernambuco. In: Menezes, R.S.C., Sampaio, E.V.S.B., Salcedo, I.H. (Eds.) Soil fertility and
345 biomass production in the semiarid. 2008; p. 27-46. Brazil.
- 346 31. Guy BT, Dickinson WT, Rudra RP. Hydraulics of sediment-land in sheet low and the influence of
347 simulated rainfall. 1990; 15:101-118.
- 348 32. Cassol EA, Cantalice JRB, Reichert JM, Mondardo A. Runoff and breakdown soil in interrill in
349 frank-clay-sandy soil with litter. Agricultural Research. 2004; v.39, n7, p.685-690. Brazil.
- 350 33. Bezerra SA, Cantalice JRB. Interrill Erosion in different soil cover conditions under sugar cane
351 cultivation. 2006; 30:565-573, 24:1697-1716. Brazil DOI 10.1007/s11269-009-9520-4.
- 352 34. Cantalice JRB, Bezerra SA, Oliveira OFL, Melo RO. Hydraulics and erosion rates in interrill under
353 different slopes and mulch doses. 2009. v. 22, n.2, p.68-74. Brazil.
- 354 35. Gerits JJP, Lima JLPD, Broek TMWVD. Overland flow and erosion. In: Anderson, M.G., Burt, T.P.
355 Process studies in hillslope hydrology. Chichester: J. Willey. 1990; p. 173-214.
- 356 36. Wainwright J. Infiltration, runoff and erosion characteristics of agricultural land in extreme storms
357 events, SE France. Catena. 1996; 26: 27- 47.
- 358 37. Food and Agriculture Organization of the United Nations - FAO. Soil erosion by water: some
359 measures to combat in farmland. 1967; 207p. Roma.
- 360 38. Schertz DL. J Soil Water Conserv. 1983; 38:10-14.
- 361 39. Bezerra SA, Cantalice JRB, Cunha MF, Souza WL. Hydraulic characteristics in rill erosion in a
362 Inceptisol the semiarid Brazil. Journal Brazilian of Soil Science. 2010; vol. 34. Brazil.
- 363 40. Knapen A, Poesen J. Soil erosion resistance effects on rill and gully points and dimensions. Earth
364 Surface Processes and Landforms. 2010; v. 35, 217-228 p.
- 365 41. Schäfer MJ, Reichert JM, Cassol EA, Eltz FLF, Reinert DJ, 2001. Erosion in rills on different
366 preparations and states soil consolidation. Journal of Soil Science. 2001; v. 25, n. 2, p. 419-430.
- 367 42. Simons DB, Sentürk F. Sediment transport technology. Fort Collins, Water Resources
368 Publications. 1992; p. 807.

- 369 43. Laflen JM, Thomas AW. Cropland experiments for the Wepp project. In: International Winter
370 Meeting of the American Society of Agricultural Engineers. Illinois. [Papers]. St. Joseph, American
371 Society of Agricultural Engineers. 1987; 14 p.
- 372 44. Flanagan DC, Ascough JC, Nearing MA, Laflen JM. The Water Erosion Prediction Project Model.
373 In Landscape Erosion and Evolution Modelling, Harmon RS. 2001; 145 –199.
- 374 45. Lafayette KPV, Cantalice JRB, Coutinho RQ. Soil erosion resistance in ravines in a sandy clay
375 loam oxisol. Journal Brazilian of Soil Science. 2011; v. 35, n. 6, p. Brazil.
- 376 46. Giasson E, Cassol EA. Relations in rills Erosion with applied flow and doses residue wheat
377 incorporated in Plinthosol frank sandy clay. Journal of Soil Science.1996; v. 20, n. 4, p. 117-
378 125.Brazil.
- 379 47. Tooth S. Process, form and change in dryland rivers: a review of recent research. Earth-Science
380 Reviews.2000; v.51. pp. 67–107.
- 381 48. World Meteorological Organization. Manual on Sediment Management and Measurement.
382 Operational Hydrology Report, n° 47. Ed. Xiaoqing, Yang.2003; Geneva, Switzerland.
- 383 49. Molinier M, Albuquerque CHC, Cardier E. Analysis of rainfall and homogenized isoietas of the
384 Brazilian Northeast 1994; 58p. Brazil.
- 385 50. Williams JR, Berndt HD. Sediment yield computed with universal equation. /. Hydraul. Div., Proc.
386 Amer. Soc. Civ. Engrs 98.1972; no.HY12, 2087-2098.
- 387 51. Nrcs – USDA. Sediment sources, yields, and delivery ratios. Washington, National Engineering
388 Handbook.1979; Section 3-Sedimentation, p.120.