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Sediment Delivery Ratio from a small Semiarid Watershed of Brazil

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ABSTRACT

Assessing technologies based on sediment yield in watersheds is increasingly important to determine the delivery rate. This work aimed to determine values of sediment delivery of the hydrographic basin of the river Jacu in the semiarid of Pernambuco and its relations with the soil and vegetation. Therefore, it was calculated the rates of interrill and rill erosion by yield testing under shrub and uncovered Inceptisols conditions, and it was carried out direct measurement campaigns of suspended sediment and bedload, by means of US DH – 48 e US BLH – 84, respectively. The sediment yield obtained in Jacu stream was considered low. The soil loss due to interrill erosion under uncovered conditions equal to 8.43 t ha⁻¹ was considered high, as well as the same way for the values of rill erosion with erodibility equal to 0.0021142 kg N⁻¹ s⁻¹ and critical shear stress 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 is associated with the natural variability of semiarid environment, indicating the necessity of assessment in a large period of years to improve the knowledge about the sediment delivery ratio of Jacu semiarid watershed.

Keywords: Water erosion, Variability in semiarid, Conservation of soil

Taxa de entrega de Sedimentos de uma pequena bacia Semi-Árida do Brasil

RESUMO

Avaliar tecnologias baseadas no rendimento de sedimentos em bacias hidrográficas é cada vez mais importante para determinar a taxa de entrega. Nesse trabalho objetivou-se determinar os valores de entrega de sedimentos da bacia hidrográfica do rio Jacu no semiárido de Pernambuco e suas relações com o solo e a vegetação. Portanto, foram calculadas as taxas de erosão entre perfurações e sulcos através de testes de rendimento sob condições arbustivas e descobertas de Inceptissolos, e foram realizadas campanhas de medição direta de sedimentos em suspensão e carga, por meio de US DH - 48 e US BLH - 84, respectivamente. O rendimento de sedimentos obtido no córrego Jacu foi considerado baixo. Considerou-se alta a perda de solo devido à erosão interrill sob condições não descobertas iguais a 8,43 t ha⁻¹, assim como para os valores de erosão de sulcos com erodibilidade igual a 0,0021142 kg N⁻¹ s⁻¹ e tensão crítica de igual a 2,34 Pa. O valor médio da razão de entrega de sedimentos da bacia hidrográfica de Jacu foi igual a 0,165 e variou de 0,29 no ano de 2008 a 0,026 em 2010. Essa variação está associada à variabilidade natural do ambiente semiárido, indicando a necessidade de avaliação em um grande período de anos para melhorar o conhecimento sobre a taxa de entrega de sedimentos da bacia hidrográfica do semiárido de Jacu.

Palavras-chaves: Erosão hídrica, Variabilidade no semiárido, Conservação do solo

Introduction

The Sediment Delivery Ratio (SDR) is the rason between the production of sediment at the outlet of the basin and the gross erosion of the basin, it was established to quantify a fraction of all sediment eroded in the area of the basin that manages to reach its outflow. The rate of delivery is a factor that relates the availability of sediment and deposition at various spatial scales in the basin and thus involves the various erosive processes, disaggregation, transport and deposition of sediments (Lu et al., 2006).

Estimates of sediment yield are needed for studies of reservoir sedimentation, river morphology, soil and water conservation planning, water quality modelling and design of efficient erosion control structures (Sarkar et al., 2017; Millare and Moñino, 2018). The Sediment Delivery Ratio acts as a reducer to equate the maximum amount of soil erosion to the sediments delivered to the outlet. SDR is a continuous variable with a range from zero to one (Wu et al., 2018).

In recent years, process-based erosion prediction models have received increasing attention for various theoretical and practical reasons. Models such as WEPP (Water Erosion Prediction Project) (Liu et al., 2017; Nicosia et al., 2019; Fernandes and Vega, 2018), GUEST (Ahamefule et al., 2018; Cheng et al., 2018) and EuroSEM (Eekhout et al., 2018, Thakur et al., 2018) as well as several others show great potential for application. The SDR is controlled by many factors, such as land use, catchment area, relief-length ratio, soil texture, transport process and gradient gradient of the main channel. Many studies have examined the relationship between SDR and the above factors (Kieu Anh Nguyen and Walter Chen, 2018).

The semiarid regions of the Brazilian Northeast, where Caatinga vegetation prevails, experience a significant variation in precipitation indices and the soils are normally very shallow, making them vulnerable to erosive processes. In several cases, depending on the distribution and intensity of the rains, soil losses may extend beyond the tolerable limits, which are around 2.5 to 5 ton ha⁻¹ year⁻¹ for shallow soils (Leite et al., 2018). In addition to the problems mentioned, deforestation is a common practice in these regions as a consequence of demographic pressures induced by a growing demand for agricultural and forestry products. Indiscriminate deforestation in order to create new farms, together with the

removal of wood for profit (construction, firewood, charcoal etc.) and the successive burns with inadequate soil management, has combined with prolonged droughts to compromise the fragile Caatinga equilibrium. The combination of these activities often results in permanent changes in hydrosedimentological processes (Lopes and Araujo, 2019). The SDR can be affected by several other factors including soil texture, slope/length, landuse, sediment source, nearness to the main stream (Pierluigi et al., 2016).

Few studies and complexity of the understanding of the processes involved in the phenomena of sediment production and sediments delivery ratio (SDR), as well as their determination, are of fundamental importance in the search for alternatives for better watershed management in semiarid regions. Therefore, an accurate prediction of SDR is an important challenge for a sustainable natural resources development and, in general, for environmental protection. The present work had as aim to determine values of sediment delivery of the hydrographic basin of the river Jacu in the semiarid of Pernambuco and its relations with the soil and vegetation.

Material and methods

Characterization of experimental área

The study area is located in the Jacu watershed between the cities of Serra Talhada and Floresta (latitude 8°07'07" S and longitude 38°23'55" W) in the semiarid environment of the state of Pernambuco, Brazil. The climate in the regions is classified as BWh according to the Köppen type hot and dry. The climate of the region, according to the Köppen classification, fits in the type Bwh, called semi-arid, hot and dry, with summer-autumn rains with an annual average of 647 mm year⁻¹ and average annual temperature above 25°C (Silva Filho et al., 2019). Precipitation data during the period of collection and monitoring of the experiment (Figure 1).

Figure 1.- Rainfall distribution for period between Years 2008 to 2011.

The soil type found Entisols in the watershed described according to the classification Santos et al. (2018). The predominant vegetation in the basin is semi-shrubland, rainfed agriculture and shrubland, with a distribution of 70.55%, 17.24% and 12.21% respectively. The physical

characterization of soil in the study area, were collected samples in the 0 – 10 cm layer, air-dried and sieved on 2 mm sieves and the apparent results are shown in Table 1 and the morphometric parameters of the Jacu watershed are showed in Table 2.

Table 1.- Physical Characteristics of Entisols in the 0-10 cm layer the Jacu watershed

GRANULOMETRIC ANALYSIS			CLASSIFICATION		
Sand	Silt	Clay	Texture	PD	BD
	%			(g cm ⁻³)	
57	21	22	Sandy loam	2.48	1.42

PD – Particules density; BD – Bulk density.

Table 2.- Morphometric parameters of Jacu watershed

CHARACTERISTICS	VALUE
Field	2.10 km ²
Perimeter	6.50 km
Length of the main channel	2.66 km
Compactness coefficient (kc)	1.26
Form factor (kf)	0.0497
maximum quota	638.9 m
minimum quota	422.4 m
Average slope of the basin	0.081 m m ⁻¹
Slope of the main channel	0.01726 m m ⁻¹
Drainage density	1.32 km km ⁻²
Order of the watershed	3rd

Hydraulic characterization of Jacu river

To measure the flowing length of the stream, was installed in the control section of Jacu River the sensor for measure flow and measuring water depths monitoring station (data logger SL2000MIM) and commenced data logging for reporting to performed a detailed site assessment of the potential achieving optimal results. Were also performed 23 campaigns direct measurements of hydraulic characteristics of speed and blade height of runoff in Jacu River. The average runoff velocity (m s^{-1}) was determined by integration of the profile, through the use of a type of current meters with propeller determine flow velocity by the number of revolutions of propeller over a given period of time.

Sediment yield (Y) of the watershed

The suspended sediment yield (Y) was calculated by solid discharge measure continuously in accordance with the procedure of the Li et al. (2020), from the sum of the collection of suspended sediment sample with the use of one of sampler's sediments (DH-48) with the collections of the bottom sediment. Both in sampling suspended sediment and in the bottom sediment was used the method of Equal Width Increment (IIL).

Production of suspended sediment and discharge solid

Samples were collected by lowering and raising a sampler through the water column at the center of each increment utilizing a DH48 sampler at equal width intervals across the stream. After collecting the suspended sediment samples were taken to the laboratory where they were dried at 60°C for the determination of the concentration values of sediment, which was obtained by evaporation method (Li et al., 2020). The values of suspended solids discharge (Q_{ss}) were determined according to the following expression (Cantalice et al., 2013):

$$Q_{ss} = \sum (C_{ssi} \cdot Q_{li}) \cdot 0.0864 \quad (1)$$

where: Q_{ss} - Suspended sediment discharge (day t^{-1}); C_{ssi} - concentration of suspended sediment vertical (mg L^{-1}) and Q_{li} - liquid discharge the respective vertical ($\text{m}^3 \text{s}^{-1}$).

The production of suspended sediment in each year (Y_{ss}) was obtained by the following expression:

$$Y_{ss} = \frac{Q_{ss} \cdot X}{A} \quad (2)$$

Where: Y_{ss} - production of suspended sediment ($\text{t km}^{-2} \text{yr}^{-1}$ or $\text{t ha}^{-1} \text{yr}^{-1}$); Q_{ss} - solid suspended discharge (t day^{-1}); X - number of days in the year (days year^{-1}) in which there was runoff in semiarid rivers with intermittent regime, A - watershed area (km^2 or ha).

Solid bedload discharge and production of bedload

The solid bedload discharge was determined from the equation established for (Kociuba, 2017):

$$Q_{sf} = \sum \frac{m}{w \cdot t} \quad (3)$$

Where: Q_{sf} - solid bedload discharge (t day^{-1}); m - mass of sediment (g); w - nozzle diameter (m); t - sampling time (s).

The production of bedload throughout the year (Y_{sf}), was obtained by the expression:

$$Y_{sf} = (Q_{sf} \cdot X) / A \quad (4)$$

Where: Y_{sf} - bedload production ($\text{t km}^{-2} \text{yr}^{-1}$, or $\text{t ha}^{-1} \text{yr}^{-1}$); Q_{sf} - solid bedload discharge (t day^{-1}); X - number of days in the year when there was runoff; A - watershed area (km^2 or ha).

Finally, the total production of sediments (Y_t) was determined by summing the production of suspended and bedload:

$$Y_t = Y_{ss} + Y_{sf} \quad (5)$$

Where: Y_t - production of total sediment ($\text{t km}^{-2} \text{yr}^{-1}$ or $\text{t ha}^{-1} \text{yr}^{-1}$); Y_{ss} - suspended sediment production ($\text{t km}^{-2} \text{yr}^{-1}$, or $\text{t ha}^{-1} \text{yr}^{-1}$); Y_{sf} - bedload production ($\text{t km}^{-2} \text{yr}^{-1}$, or $\text{t ha}^{-1} \text{yr}^{-1}$).

Interrill erosion

Rainfall simulator 80 - 150 Veejet nozzles on the simulator produced, according to Kaviani et al. (2018), rainfall having an impact energy of 2750 kJ was developed in laboratory of Management Soil Conservation employed to overcome difficulties to measure erosion rates and was used in interrill simulators and reproduce a distribution of droplet size and levels of kinetic energy near the natural rainfall, operating at a constant water pressure in outlet nozzle of 41 kpa. The rainfall simulator was supplied by a submersible pump placed in a water tank 1000 L. The average rainfall intensity 90 mm h^{-1} was measured using a set of 10 pluviometers placed at random within and adjacent to the working area of the experimental plots.

Three treatments: T_1 - soil with semi-shrubby Caatinga vegetation; T_2 - soil with herbaceous residue in decomposition and T_3 - soil uncovered, with replicated three times. Representing three likely conditions typical of interrill erosion in watershed. The plots consisted of an area of 1 m wide and 2 m long, with the longer dimension in the direction of the slope, and are bounded by galvanized sheet metal 30 cm, driven into the ground at 20 cm depth. Galvanized collectors were installed prior to rainfall simulation at the downhill side of the plot.

Rill erosion

The pre-formed rill was delimited laterally by placing zinc metal sheets were buried subjected to erosion tests applied with four flow levels: T_{F1} - 14.95 L min^{-1} ; T_{F2} - 28.70 L min^{-1} ; T_{F3} - 39.85 L min^{-1} ; T_{F4} - $67.405 \text{ L min}^{-1}$ in four replications randomly and for twenty minutes (Cantalice et al., 2013). The flow velocity (m s^{-1}) was determined by multiplying the values obtained during testing of surface velocity by a correction factor $\alpha = 0.6$. The slope of the 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} (Cantalice et al., 2013).

The perimeter of the section when combined with the cross-sectional area of rills, provided the hydraulic radius used to calculate the shear stress of the flow from the formula described below:

$$R_h = A / P_m \quad (6)$$

Where, R_h - Hydraulic radius (m); A - cross sectional area of the rill (m^2); P_m - the wetted perimeter of the rill (m).

From the mass of dry soil and the duration of sampling were determined rates of breakdown of soil in the rill, obtained by the following grating described by Cantalice et al (2019):

$$D_r = (Q \cdot C) / (L \cdot P_m) \quad (7)$$

Where, D_r - detachment rate of soil in rill ($\text{kg m}^{-2} \text{ s}^{-1}$); Q - liquid discharge (L s^{-1}); C - concentration (kg L^{-1}); P_m - wetted perimeter (m) and L - length of the rill (m).

Assuming that the erosion of rill with the addition of flow, sediment load is much greater than the transport capacity, was used the capacity

of the equation breakdown of flow in rill (D_c) for determining the momentary rate breakdown of the flow, expressed by Brooks et al. (2016):

$$D_c = K_r (\tau - \tau_c) \quad (8)$$

Where, D_c - capacity to breakdown the flow in rill ($\text{kg m}^{-2} \text{ s}^{-1}$); K_r - soil erodibility in rill ($\text{kg N}^{-1} \text{ s}^{-1}$ or s m^{-1}); τ_c - critical shear stress of the soil (N m^{-2} or Pa); below which there is no breakdown, and τ - flow shear stress (N m^{-2} or Pa);

The soil losses were calculated from the data of instantaneous sediment concentration of runoff and the rate liquid of discharge by the expression below by Cantalice et al. (2019):

$$P_s = (\sum (Q_{in} \cdot C_{in} \cdot t)) / A \quad (9)$$

Where, P_s - total loss of soil (kg m^{-2}); Q_{in} - liquid discharge rate (L min^{-1}); C - concentration of sediments (kg m^{-1}); t - time between samples (min) and A - area of the rill m^2 .

Statistical analysis

The experimental design was completely randomized is the simplest type of randomization scheme in that treatments are assigned to units completely by chance in three replicates of each treatment. Statistical analysis was performed with the SAS Statistical Program. For the comparisons between the means were performed by the Tukey test, at 10% of significance. It was used Curve Expert for compares regression models through data entry, analysis and graph display of best fit corresponding of equation.

Results and discussion

In the Table 3, values of hydraulic roughness for the conditions of vegetation were higher in uncovered soil, justifying the reductions in speed and flow in these conditions and prove that the elements in the of vegetation in form dossal of caatinga vegetation and residue in contact with soil gave rise to physical and hydraulic resistance to runoff. This result leads us to agree with Hou et al., 2020 that we shouldus to to make the population aware of soil protection, in which the majority of people living in poverty live in rural areas, where agricultural production is an essential source of income, and that in these areas the health of the Soil is a decisive factor for productivity and income levels (Hou et al., 2020).

Table 3.- Hydraulic characteristics of runoff under conditions of caatinga vegetation in the watershed of Jacu river

VARIABLES	TREATMENTS		
	T ₁	T ₂	T ₃
q (m ² s ⁻¹)	1.4 x 10 ⁻⁵ B*	1.9 x 10 ⁻⁵ A	2.9 x 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
R _e (adm.)	17.46 ns	22.36 ns	34.58 ns
F _r (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 each other, the 5% level of significance, the Tukey test. T₁ - soil with semi-shrubby Caatinga vegetation; T₂ - soil with herbaceous residue in decomposition; T₃ - soil uncovered; q - liquid discharge; h - blade height of the runoff; V- runoff velocity; R_e - Reynolds number; F_r - Froude number; log_f - hydraulic roughness

Similar results were observed by Piscoya et al. (2018a); Silva et al. (2017), The flow Reynolds number were T₁ = 17.46; T₂ = 22.36; T₃ = 34.58 and froud number T₁ = 0.2391; T₂ = 0.1466; T₃ = 0.5368. Thus, these characterize a laminar and subcritical flow regime, as indicated by the values of R_e < 500 e F_r < 1, respectively, typical of interrill erosion flow conditions (Cantalice et al. 2019).

Soil cover influence in soil surface roughness and the runoff provided by the caatinga vegetation semi-shrub and the litter on soil, so that the soil disaggregation is considerably reduced but, retains water on its surface and decreases runoff volume and velocity compared the condition of uncovered soil. Similar results were obtained by Silva et al. (2020) evaluating the effect of different levels of coverage soybean straw on interrill erosion and runoff. The infiltration rates higher

showed for soil with semi-shrubby Caatinga vegetation and soil with herbaceous residue in decomposition due roughness height decrease runoff volume favoring to water infiltration capacity, soil roughness potentially affects surface processes such as infiltration (Piscoya et al., 2018b; Dumbrovsky et al., 2019).

The caatinga vegetation and litter in soil will develop a high degree of contact increased opportunities for infiltration slowing it down, giving more time for infiltration and will substantially slow down the speed of runoff flow, generally resulting in reduced volumes of runoff (Table 4). This was confirmed by the elevation roughness (f) and infiltration rates. Water stored in the foliage, giving more time for infiltration and so reducing the volume of runoff (Menezes et al., 2019).

Table 4.- Soil loss in interrill obtained under conditions of caatinga vegetation in watershed of Jacu river

Variables	Treatments		
	T ₁	T ₂	T ₃
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
Di (Kg m ⁻² s ⁻¹)	8 x 10 ⁻⁵ B	4 x 10 ⁻⁵ B	3.2 x 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). T₁ - soil with semi-shrubby Caatinga vegetation; T₂ - soil with herbaceous residue in decomposition; T₃ - soil uncovered; C - runoff coefficient; D_i - detachment rates soil in interrill; P_s - soil loss.

The effect of elevation roughness by the vegetation was reflected in reduced erosion rates, the instantaneous breakdown rate of soil and the soil losses. The protection degree of soil by T_1 and T_2 allowed soil losses within tolerable limits protecting the soil to prevent erosion than T_3 similar relationships were obtained by Silva Filho et al. (2019).

The soil loss T_3 were much higher than those observed by the conditions of T_1 , constituting very high losses for young soils poorly developed

profiles and caatinga's vegetation deciduous include total loss of leaves during the dry season. The results also showed that soil losses were considered very low in ton year ha^{-1} (Piscoya et al., 2018a).

Soil hydraulic flow behaviour using preformed rill for erosion experiments in adding clear water inflow at different rates applied to the plots showed the values of Reynolds numbers (Table 5).

Table 5.- Different discharge rates applied to the upper end of rills preformed for determining soil erodibility parameters

VARIABLES	DIFFERENT DISCHARGE RATES (L MIN ⁻¹)			
	T_{F1}	T_{F2}	T_{F3}	T_{F4}
Q (L min ⁻¹)	12.465 B*	26.135 B	36.554 A	58.723 A
V_m (m s ⁻¹)	0.182 B	0.238 A	0.280 A	0.310 A
S (m m ⁻¹)	0.049	0.051	0.052	0.052
R_e (adm.)	1,920.21 B	5,252.53 A	5,132.24 A	4,522.30 A
F_r (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 ($p < 0.05$). T_{F1} - 14.95 L min⁻¹; T_{F2} - 28.70 L min⁻¹; T_{F3} - 39.85 L min⁻¹; T_{F4} - 67.405 L min⁻¹; Q - liquid discharge; V_m - mean flow velocity; S - slope in rill plots preformed; R_e - Reynolds number; F_r - Froude number; $\log f$ - hydraulic roughness.

Above 2500 for the larger values of flows applied between T_{F2} and T_{F4} , characterized the regime of runoff as turbulent flow, and the lower flow applied of T_{F1} generated a regime transitional runoff (Cantalice et al., 2019), tranquil or subcritical flow. The average gradient slope in rill plots and roughness the Darcy-Weisbach coefficient no showed differences statistically significant.

The shear stresses obtained differed significantly when compared discharge applied low flow with higher flows dependent of variation of hydraulic radius causing different breakdown rates of due soil larger flows applied T_{F3} and T_{F4} (Table 6). Similarly, soil losses were higher already from the second level of flux T_{F2} and T_{F4} considered high values for soils normally very shallow and places extreme variability environmental.

Table 6.- Soil loss rill under simulated rainfall in watershed of Jacu river

ERODIBILITY PARAMETERS	DIFFERENT DISCHARGE RATES (L MIN ⁻¹)			
	T_{F1}	T_{F2}	T_{F3}	T_{F4}
τ_c (Pa)	4.376 B	5.128 A	6.285 A	13.079 A
D_r (kg m ⁻² s ⁻¹)	0.0028 B	0.0053 B	0.0096 A	0.0246A
P_s (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 ($p < 0.05$). T_{F1} - 14.95 L min⁻¹; T_{F2} - 28.70 L min⁻¹; T_{F3} - 39.85 L min⁻¹; T_{F4} - 67.405 L min⁻¹; τ_c - critical shear stress of the soil; D_r - detachment rate of soil in rill; P_s - soil loss.

The rill erodibility values obtained was higher than those determined by Sousa and Ferreira (2017) for an Oxisols, and Brito et al. (2020) for Ultisols. This higher value is justified by the fact that this Entisols in the semiarid regions are young soil, generally shallow and weakly developed soils, than the Oxisols and Ultisols commonly found. The value of the critical shear stress of 2.34 was also lower than those determined by various Ultisols (Bruto et al., 2020) and this discrepancy should be justified by this Entisols be weakly evolved and soil particle size distribution with enough sand providing less shearing resistance action caused by the concentrated runoff.

The Sediment yield ranged from 0.45 to $1.72 \text{ t}^{-1} \text{ y}^{-1}$ and was considered low values for four

years (Table 7). The respective amounts of suspended sediment concentration ranged 874 to 376 mg L^{-1} was considered high for a small watershed and low values of the discharged liquid. The sediment concentration values of water courses in semiarid regions have behaviours differentiated when compared with events in humid climates (Piscocya et al., 2018b; Silva et al., 2018). In these regions the vegetation promotes a limitation in the production of sediments, while in the dry regions the vegetation not promotes an efficient coverage soil thus allowing the generation of large volumes of sediment being carried by runoff coming to waterways (Lu et al., 2019).

Table 7.- Values average discharged liquid, discharge suspended solid and bottom discharge determined in the period between 2008 to 2011

YEAR	Q	CSSi	X	Qss	Qsf	Yss	Ysf	Yt	Yt
	m ³ s ⁻¹	mg L ⁻¹	days	t day ⁻¹			t ha ⁻¹ year ⁻¹		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

Q – discharge; C_{SSi} - suspended sediment concentration; X – time; Q_{ss} - discharge suspended solid; Q_{sf} - solid bedload discharge; Y_{ss} - production of suspended sediment; Y_{sf}: bedload production; Y_t: production of total sediment.

The Jacu watershed showed the average suspended sediment concentration 874.53 mg L^{-1} for a period only 45 days of flow in 2010. The pattern rainfall distribution in simple peaks events unimodal or bimodal with interannual variation characterizing the pattern of rainfall in arid and semiarid regions. The production of sediments was

considered low by the standards adopted by the Han and Gao (2019) for the transport of sediment limited by climate, in intermittent waterways.

The Sediment delivery ratio values for the watershed Jacu river to 2008 to 2011 were obtained from total sediment production (Table 8).

Table 8.- Sediment delivery ratio measured for period 2008 to 2011

YEAR	* SDR
2008	0.291
2009	0.265
2010	0.026
2011	0.076
Average	0.165

*Adimensional; SDR - Sediment delivery ratio

The quantitative fraction all sediment broken down and transported, but which in reality came to be transported out of the watershed SDR varied from 0.291 in the year 2008 to 0.026 in 2010. During this period the 2010 year presented the most irregular rainfall distribution, with a low total annual value of 370.55 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 (Li et al., 2020), giving the rains to arid and semi-arid high spatial and temporal variability, and still interannual variability rising with aridity. Reinwarth et al. (2019) reports that values of the magnitude of the SDR tends to increase with the area being the maximum 30% or 0.3 to watershed 0.5 to 5.2 km² and ranging from 0.1 to 0.38.

The results agree with Swarnkar et al., 2018 where researches similar developed in Garra River basin, India provide also a systematic procedure is provided for evaluating of gives SDR. The novelty of the work lies in presenting a unified framework for quantifying the Sediment Delivery Ratio (SDR). Values for Nanak Sagar Dam (NSD) and Husepur gauging station (HSG) are estimated to be 0.63 and 0.45, respectively. Lower SDR values were found in the Jacu River basin measured from 2008 to 2011 due to lower erosion rates.

Conclusions

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 for interrill erosion in uncovered soil of 8.43 t ha⁻¹ were high, as well as the rill erosion with rill erodibility 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 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.

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