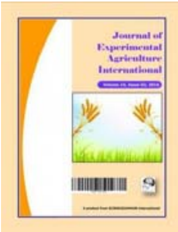

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Riparian Buffer Strip Width Design in Semiarid Watershed Brazilian

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Studies assessing technologies to design riparian strips using plant covers, based on sediment yield in river basins, are required for environmental protection. The removal of semi-shrubby, native vegetation in the Brazilian semiarid region, has contributed to the degradation of semiarid basins. The aim of this study was to design a riparian strip for the Jacu River in the semiarid region of Pernambuco as a function of sediment yield. Experiments were conducted during the years 2008-

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2011 in the Jacu River basin at Serra Talhada, Pernambuco State, Brazil. The sediment yield in the Jacu River channel was obtained by measuring suspended and background solid discharge. The riparian strip width estimated in the riparian areas of the Jacu River basin was 15 m. It was concluded that for this study, the sediment yield time and observation of hydrological data were important factors for determining the riparian strip width with greater security.

Keywords: Riparian vegetation; degradation; erosion; soil conservation.

1. INTRODUCTION

Studies for assessing technologies to design riparian strips using plant covers, based on the sediment yield in river basins, are needed for environmental protection. Some forms of riparian strips are agricultural landscape features that have arisen as a result of an environmental law or are areas that are difficult to work [1]. Some authors reported that large permanent vegetation strips produce an effective reduction of pesticides carried by runoff, because of the ability of vegetation to slow runoff and promote water infiltration and adsorb herbicides, these strips can improve the quality of water and produce additional environmental benefits when used with other soil management practices [2].

The use of riparian areas as water quality management tools, primarily derived from the studies of agricultural watersheds, where low phosphorus and large nitrate reductions in the suspended sediment are observed [3] and [4], in addition to influencing the processes of direct flow generation due to rain, peak flood attenuation, runoff power dissipation due to the roughness of banks, heat water balance, stability of banks and ravines, nutrient cycling, and sediment control [5].

A riparian strip performs many key functions, such as nutrient uptake, trapping of sediment or pesticides. Therefore, a number of different forms of protection strips have been applied in the field according to relief, steepness and location for use. In addition to capturing nutrients and sediments, riparian strips can provide multiple benefits in terms of biodiversity and water regulation. However, the current practice conceptualizes landscape components interacting with a range of goods and ecosystem services [6]. Vegetation strips or buffer strips represent a soil conservation technique of low potential for reducing the transport of pesticides by runoff from adjacent agricultural areas to water bodies [7].

Studies have shown that the buffer function of a riparian strip is complex because not all factors can be fully controlled and the final destination of chemicals is closely related not only to their chemical properties but also with the characteristics of events, such as rain, harvest and plant cover conditions [8]. Much has been currently discussed in riparian areas forming part of plant systems essential to environmental balance, representing, therefore, a central concern for sustainable rural development.

Despite their undeniable environmental importance, riparian forests have been eradicated in many parts of Brazil. There are a few major studies on a micro experimental watershed which provide limited information for the development of hydrological and sedimentological criteria that can be utilized to determine the minimum riparian strip width in a riparian zone in order to ensure the protection of waterways [9]. On the other hand, the Brazilian Forest Code of 1965 only presents strict limits of width for vegetation strips on watercourses and does not define scientific criteria for determining the width of riparian areas.

Accordingly, we must review our methodologies to design, understand and evaluate riparian buffer strips to maximize their potential benefits, which should be according to local needs, pressures and landscape. It is necessary to consider the vulnerability of a number of watershed areas to prioritize resources for the design of effective riparian strips. This may involve evaluating vulnerable ecological function areas and intensive farming areas [1].

Studies are needed, especially in areas with steep slopes and subjected to intensive land use that will help determine the width of vegetation strips for the restoration of riparian vegetation using dense vegetation cover of variable width that is able to retain soil losses [10]. There is a critical need for field assessment to validate models of erosion simulation and production of sediment in river watersheds with the objective of determining riparian strip widths [11]. The objective of this study, therefore, was to design a riparian buffer strip for the Jacu River in the semiarid region of Pernambuco, Brazil as a function of sediment yield and test it using field data.

2. MATERIALS AND METHODS

2.1 Location and Characteristics of the Experimental Area

The study was conducted in the Jacu River basin located within the municipal boundary between cities of Serra Talhada and Floresta, forming part of the São Pedro River watershed and part of the Pajeú River watershed, both in the state of Pernambuco, with an area of 2.10 km^2. The watershed is limited by the coordinates latitude -8º07'55" S between -8º09'07" S and longitude -38º23'20" W between -38º24'14" W.

The characteristic climate is Bwh type - tropical climate called semiarid, warm and dry, with summer-autumn rains, according to the Köppen classification, with average annual rainfall of 484.06 mm yr^{-1} for the period from 1992 to 2007 and average annual temperature above 25°C with summer rains that delay to fall and extend to April [12].

In the study area, there is a predominance of Entisol Fluvent [13], with limitation regarding the water storage capacity due to the higher percentage of sand in these soils, especially in those the coarse sand predominates over thin sand.

2.2 Physical and Water Parameters of the Jacu River Watershed

The physical and water parameters of the watershed were obtained from the Shutlle Radar Topography Mission image processing, SC.24-X-A (1: 250,000), as shown in Table 1.

2.3 Vegetation and Use of the Jacu River Semiarid Watershed

For preparing the vegetation chart for the Jacu River basin, photo interpretation techniques were used over a GEOCOVER image [14], corresponds to a mosaic of Landsat images that were orthorectified and processed with a high quality standard (Geo Cover Technical Guide) adopted for the georeferencing of other orbital products suggested by [15-18]. In the case of the Jacu River watershed, the chart was based on the individualization of vegetation type units (shrub semi-shrubby and upland agriculture) and used according to their tonal and textural characteristics with prior field verification to validate the results obtained in the initial stage. The values obtained as a result of quantification of the vegetation chart and use in the Jacu River watershed are shown in Table 2.

Table 1. Physical and water parameters of the Jacu River semiarid basin

Parameters	Value
Area	2.10 km^2
Perimeter	6.50 km
Basin length	2.00 km
Form factor	0.0497
Length of main channel	2.66 km
Vector distance from the main channel	1.85 km
Number of channels in the basin	34 channels
Basin order	Third order
Number of 1st order channels	26 channels
Number of 2nd order channels	7 channels
Number of 3rd order channels	1 channel
Total length of channels	11.06 km
Average length of channels	0.43 km
Drainage density	1.32 km/km^2
Hydrographic density	12.38 channels /km^2
Compactness coefficient	1.26
Highest basin altitude	638.9 m
Lowest basin altitude	422.4 m
Altimetry amplitude of the basin	216.5 m
Steepness of the main channel	17.26 m/km
Concentration time	0.984 hour

Table 2. Distribution of vegetation classes and use in the Jacu river semiarid basin

Interval	Area (m^2)	Soil use (%)
Shipht cultivation upland	364.611	17.24
Shrubby	258.248	12.21
Semi-shrubby	1.492.411	70.55
Total	2.115.270	100.00

Table 3. Soil physical characterization at depths of 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm in the Jacu River basin

Depth	D_s	D_p	Sand	Silt	Clay	Total porosity	Texture
	g cm^{-3}		------------	g kg^{-1}	------------	%	
0 -20	1,14	2,59	72,94	18,61	8,46	55,9	Sandy clay loam soil
20-40	1,20	2,50	66,48	23,65	9,87	52,0	Sandy clay loam soil
40-60	1,13	2,66	72,88	17,39	9,74	57,5	Sandy clay loam soil
60-80	1,17	2,63	75,33	15,76	8,91	55,5	Sandy clay loam soil

D_s = soil density; D_p = particle density

Table 4. Chemical characterization of soil in the Jacu river semiarid watershed collected at depths of 0-20 cm, 20-40cm, 40-60 cm, 60-80 cm

Sorption complex	Depth (cm)			
	0 - 20	20 - 40	40 - 60	60 - 80
	Exchangeable cations			
Ca^{2+} ($cmol_c$ kg^{-1})	0.52	0.57	0.50	0.67
Mg^{2+} ($cmol_c$ kg^{-1})	0.35	0.31	0.35	0.35
Na^+($cmol_c$ kg^{-1})	0.27	0.25	0.58	0.38
K^+($cmol_c$ kg^{-1})	0.16	0.57	0.50	1.35
SB ($cmol_c$ kg^{-1})	1.30	1.70	1.93	2.75
PST (%)	13.09	10.63	21.89	14.97
CTC (%)	2.0	2.11	2.42	3.05
	Soluble cations			
pHes	7.30	7.20	7.05	7.02
CE(dS m^{-1})	1.41	2.07	4.28	6.70
Ca^{2+} ($mmol_c$ L^{-1})	0.85	1.02	1.71	1.72
Mg^{2+} ($mmol_c$ L^{-1})	0.35	0.45	0.90	0.99
Na^+($mmol_c$ L^{-1})	8.13	15.23	45.31	77.91
K_+($mmol_c$ L^{-1})	1.10	1.41	2.54	3.09
Cl^-($mmol_c$ L^{-1})	7.60	10.91	11.69	10.60
RAS ($mmol_c$ L^{-1})^{0,5}	10.19	16.18	32.45	54.84

2.4 Soil Physical and Chemical Characteristics

For characteristics physical Table 3 and chemical characteristics Table 4, samples were collected at depths of 0-20 cm, 20-40 cm, 40-60 cm, and 60-80 cm; air dried; crushed; homogenized; and passed through a 2 mm mesh. The particle size distribution was determined using the test tube method, and the particle density was obtained using the volumetric flask method and volumetric moisture [19]. The soil density was determined by the volumetric cylinder method [20]. The total porosity was obtained following the expression:

$$P_t = \left(1 - \frac{D_s}{D_p}\right) . 100 \quad (1)$$

where P_t = the total porosity expressed in percentage (%); D_s = the soil density (g cm^{-3}), and D_p = the particle density (g cm^{-3}).

For the chemical characteristics of soil samples were determined, soluble cations and exchangeable cations [21], as presented in Table 4.

2.5 Determination of the Jacu River Riparian Strip Width

The Jacu River riparian strip width was determined using the equation proposed by [22]and [10], which is appropriate for designing the width of vegetation strips in riparian areas to protect streams from high sediment and attached nutrient loss from hillslopes in areas of intensive land use on sloping ground. We argued that the filter strip should be a dense ground vegetation cover. The strip should be of variable width designed for the incoming discharges and sediment loads. The equation, which depends on the slope area and annual soil loss, can be expressed as:

$$w=Y+\frac{1}{\rho_g H_g}\left[\left(\frac{Aa}{l_s}\right)-\left(\frac{\rho_b H_b^2}{2\tan\theta}\right)\right] \quad (2)$$

where a = the riparian area (ha); A = the sediment yield of the basin (t ha^{-1}); B = the deposited sediment weight (t); G = the sediment storage capacity of the vegetation (t); w = the width of the permanent vegetation strip (m); I = the strip length (m), l_s = deposit width (m), Y = the additional width required for sediment accumulation (m), ρ_s = the mean deposit density (tm^{-3}), ρ_g = the height of sediment deposit across the strip (m), H_g =the plant height (m) H_b = height of the sediment deposit across the strip (m) or sediment deposited in front of the vegetable strip (m), tanθ = slope angle tangent, and w = the riparian strip width (m). The weight of sediment accumulated in the vegetation strip B is the deposit volume (m^3) multiplied by the average deposit density (tm^{-3}). The sediment storage capacity of the vegetation strip is G (t).

The extent of sediment deposition over the riparian strip is much smaller than the total length of riparian area (l), due to the convergence of flow in preferential flow paths which can be expressed as a flow convergence factor (C) defined as:

$$C=\frac{l}{l_s} \quad (3)$$

where I = the strip length (m), and Is = = the deposit width (m).

Substituting equation (3) into equation (2), the result is

$$w=Y+\frac{1}{\rho_g H_g}\left[\left(\frac{cAa}{l}\right)-\left(\frac{\rho_s H_b^2}{2\tan\theta}\right)\right] \quad (4)$$

Equation (4) was used in the calculation [10] recommend y = the additional width of 2 m for moderately erodible soils and 5 m for very erodible soils.

3. RESULTS AND DISCUSSION

3.1 The Jacu River Basin Characterization

The Jacu River semiarid basin has an area of 2.10 km^2, which covers the entire area drained by the river system [23]. The basin has a form factor of 0.0497 and a drainage density of 1.32 km / km^2 [which shows that the basin has an average drainage] (Table 3). The density can vary from 0.5 km / km^2 for basins with poor drainage to 3.5 km / km^2 or more for well-drained watersheds [24]. The roughness value obtained for the basin was 0.2 due to its sparse vegetation cover, with small areas of shrubby arboreal caatinga (moderately uncovered) with upland crops in the rest of the area and extensive breeding of small animals.

3.2 Design of the Jacu River Riparian Strips

The sediment yield (Y) was calculated by the solid discharge obtained in the exudate according to the procedure of [25], from the sum of the sample collections of suspended sediment with the use of one of the sediment samplers (US DH-48), with the collection of bottom sediment. For both the suspended sediment sampling and the bottom sediment sampling, the Equal Width (IIL) method was used.

The sediment yield (Y) ranged from 0.45 to 1.72 t y^{-1} and was considered to have low values for 4 years. The respective amounts of suspended sediment concentration (SSC) ranged from 874 to 376 mg L^{-1}, which was considered high for a small watershed and for low values of the discharged liquid [26]. The sediment concentration values of watercourses in semiarid regions exhibited different behaviors when compared with events in a humid climate. In these regions, vegetation is limited by the production of sediment, while in the dry regions vegetation does not promote an efficient coverage of soil, thus allowing the generation of large volumes of sediment being carried by runoff coming to waterways [27].

Table 5 shows the riparian strip widths designed, following the method of [22] and [10], for the Jacu River according to the sediment yield in the period from 2008 and 2011. For design, the sediment deposition area was 30 m for calculating the convergence factor (C), the soil density and density of particles were obtained from the flow depth of 0 to 20 cm (Table 3), the average plant height was 1 m. and the sediment deposit height was 0.1 m.

Table 5. Width dimension (ω) of riparian vegetation strips in the Jacu River as a function of sediment yield (Y) [according to Karssies & Prosser (1999; 2001)]

Year	Y	W – Riparian strip width
	(t ha^{-1})	(m)
2008	1.722	15.35
2009	1.568	14.40
2010	0.152	5.71
2011	0.451	7.54

Y = sediment yield in Jacu River basin in 2008 to 2011 (Piscoya, 2012)

It was observed that the dimensioning of riparian strip width for the Jacu River watershed was correlated to the sediment yield values that inherited the variability associated with the distribution pattern of precipitation and local runoff. However, this variation in riparian strip width values is not a disadvantage, since the values that should be considered for the Jacu River watershed are the highest.

Although the values of 15 meters for the riparian strip width were indicated, based on the sediment yield determined for the period 2008-2011 and the interaction of hydrological, physical, soil, climate and vegetation factors, these are not yet final. The 4-year period is possibly not enough to capture the whole range of variability of the semiarid region, requiring the observation of hydrological data and production of larger sediments in order to have a more conclusive riparian strip value for the Jacu River [10] presented widths of 26 m. for all erosion rates in the range 40 t ha^{-1}.

Inácio [28] also applied the methodology of [10] in experimental plots and obtained riparian strip widths ranging from 5 to 10 m, respectively, for slopes between 4 and 38% for watercourses in southern Bahia.

Researches such as [29] speculated that the vegetation strips in riparian areas in the form of dense strips of grass or even of shrubby vegetation are considered effective in controlling sediment transport; however, many of these strips have been established in experimental plots, and rarely have been evaluated at the river basin scale, which is important in assessing the real impact of these strips on the control of siltation and water quality of rivers. Thus, [29] evaluated the effectiveness of these strips applied in isolation in river basins and suggested that for use in river basins, vegetation strips should be accompanied by other practices to reduce sediment loads in rivers and the gross erosion on slopes in order to maintain their efficiency.

4. CONCLUSION

The determination of the Jacu River riparian strip width using the Karssies Prosser method, based on sediment yield, seems to be promising for the conditions of a small river basin.

The value of riparian strip width considered in this study for the riparian areas of the Jacu River basin is 15 meters.

The sediment yield time and observation of hydrological data are important factors for the determination of riparian strip width with greater security.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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