Suspended sediment dynamics and transport into the Babitonga Bay, southern Brazil

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Abstract This study aims to estimate suspended sediment yield entering the Babitonga Bay, an estuarine system located on the southern coast of Brazil. Discharge and suspended sediment were monitored monthly in nine watersheds over a period of three years. Monitoring was accomplished on a more frequent basis in the major watershed with monthly, daily, and hourly measurements and sampling. The discharge and suspended-sediment values for each watershed were compared with morphology and morphometry, rainfall, and land-use data. The studied watersheds show distinct hydrological and sedimentological features leading to specific signals of suspended sediment yields for each individual watershed contributing to the overall sediment budget of the bay.

Key words suspended sediment; discharge; Babitonga Bay, Brazil

INTRODUCTION

The production, transport, and deposition of sediments represent one of the remarkable facts of nature, linked to the transformation of the land surface and regulated by local environmental conditions. Studies of the hydro-sedimentological behaviour of rivers in various environments, under different climatic, geological, biogeographical, and socio-economic conditions indicate that concentrations of suspended sediments in fluvial systems vary with time, space, and scale.

Few studies regarding suspended sediment dynamics have focused on Brazilian subtropical environments. The need to understand the heavy and increasing aggradation of the Babitonga Bay in recent decades stimulated an investigation of the suspended sediment dynamics and transport in the main rivers that flow into the bay. Suspended sediment may correspond up to 99% of the total solid load transported by a river in major rainfall events (Christofoletti, 1981), and from 70% to 90% of the usual sediment load of a river (Suguio & Bigarrella, 1990; Carvalho, 1994).

The Babitonga Bay is an estuarine system situated on the southern coast of Brazil and is composed mainly by three different environments: the coastal plain, the escarpments of the Serra do Mar mountain range, and the Atlantic Plateau, with an altitude range from sea level to 1520 m. The diversity of structural and morphological features has a strong influence both on river dynamics and in the rainfall distribution pattern. The study area includes seven small watersheds (rivers Braço, Canela, Bonito, Turvo, Cupim, Sete Voltas and Onça), two medium sized (rivers Pirabeiraba and Três Barras) and a 394 km^2 major basin (River Cubatão), together forming an area of 587 km^2, or 43% of the total contributing area of the bay (Fig. 1).

METHODS

Discharge and suspended sediment were monitored monthly in all watersheds, at selected points on the coastal plain but always at low tide, over a period of three years from May 2003 to May 2006. This monitoring was accomplished on a more frequent basis in the major watershed, with some daily and hourly measurements and sampling. For discharge measurements, the middle section method was adopted (Santos *et al.*, 2001) and for suspended sediment sampling the equal-width-increment (EWI) method (IOS, 1977; Edwards & Glysson, 1999). The collected water samples were filtered with pre-dried and weighed 0.45 μm ester-cellulose membranes in order to estimate the suspended sediment content.

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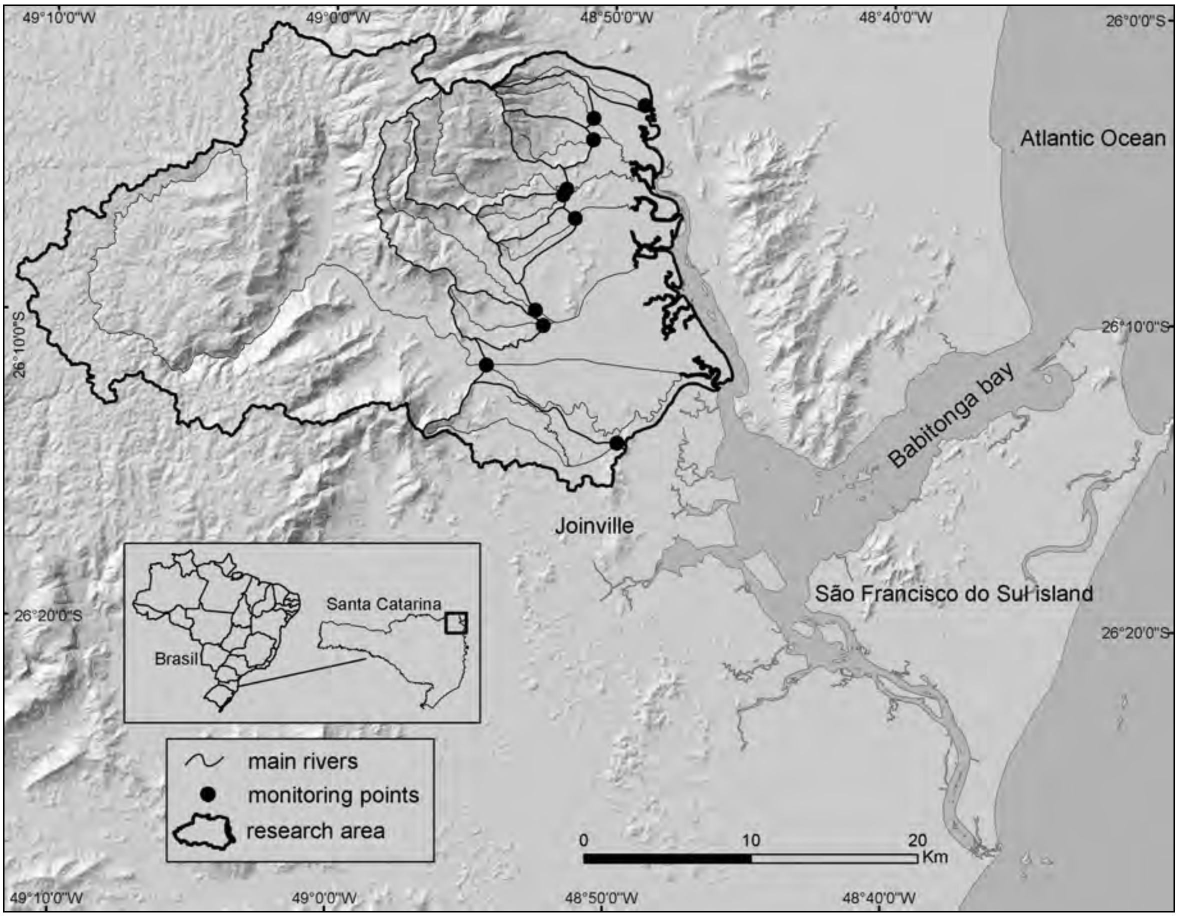

Fig. 1 Location of the research area with monitoring points and the ten studied watersheds.

RESULTS AND DISCUSSION

It must be emphasized that the analysis of a 60-year historical precipitation data series from 22 different climate stations around the research area indicates that the monitoring took place in a somewhat dry to normal period. While the mean precipitation for the whole area is 2060 mm/year, the average precipitation of the study period was 1899 mm/year, considering the rather uneven rain distribution among the different environments.

The physical environment

The studied watersheds can be divided into three groups. The first includes the major and mid-size watersheds, which occupy all topographic compartments of the study area. The second group is the smaller watersheds that occupy the escarpments and the coastal plain. The third is represented by the River Braço watershed, which occurs only on the coastal plain. This arrangement determines a different exposure of the watersheds to rainfall distribution, which is more concentrated along the escarpments and less intense in the plateau areas.

The coastal plain is occupied mostly by pasture/agricultural areas and urban settlements, while the escarpments are densely vegetated, and the plateau is characterised by both pasture/agricultural and forest areas.

The mapping of rainfall distribution through linear interpolation (ordinary kriging) of the annual mean values, and of land use through satellite image (Landsat TM5) classification, enabled the comparison of the different classes of each theme among the watersheds in terms of area occupied in km^2 (Table 1). These area values were later transformed into percent values for better comparative visualisation.

Table 1 Comparative synthesis of the area (km^2) occupied by each class of the themes precipitation and land use. From left to right, watersheds are displayed in size order.

Class	Cubatão	Três Barras	Pirab eiraba	Braço	Cupim	Canela	Onça	Sete Voltas	Turvo	Bonito
Precipitation (mm)										
<1900	1.21									
1900–2100	48.08			2.8						
2100–2300	169.3			9.2						
2300–2500	117.78	36.1	25.8	23.47	2.64	10.61	9.22	4	2.94	7.97
>2500	57.85	10.75	14.39	0.59	10.45	2.29	3.47	8.27	7.1	0.31
Land use										
Water	0.85		0.06	0.13						
Agriculture/pasture	42.25	1.72	6.57	14.92	2.72	4.59	2.79	2.16	2.78	4.73
Forest	331.36	37.77	30.86	11.99	9.28	7.18	7.29	9.07	5.97	2.77
Urban	1.63	0.1	0.55	7.6	0.56	0.84	1.18	0.64	0.23	0.21
Reforestation	5.95									
Rice fields		0.56	0.39	1.41	0.53	0.28	1.43	0.28	1.05	0.81
Fields	14.39	6.7	1.77		0.01		0.01	0.12		

The River Braço watershed shows the largest area occupied by urbanization (7.6 km^2 or 21.08%), followed by River Onça watershed (1.18 km^2, 9.28%). The smallest proportional urban areas are found in the watersheds of the rivers Três Barras (0.1 km^2, 0.21%) and Cubatão (1.63 km^2, 0.41%).

Discharge and suspended sediment

The largest mean discharge values recorded in the monitoring period were: Cubatão (12.4 m^3/s), Três Barras (3.53 m^3/s) and Pirabeiraba (1.96 m^3/s), and for the River Braço (2.25 m^3/s). Other rivers show lower discharges (Fig. 2; Table 1).

However, the highest suspended sediment values were found in the Braço (53.5 mg/L) and Onça (42.7 mg/L). The Canela, Bonito, Turvo and Cupim show values three to four times lower, while the remaining rivers present very low values. It is significant that the three largest watersheds deliver proportionally the lowest sediment load (Fig. 2; Table 2).

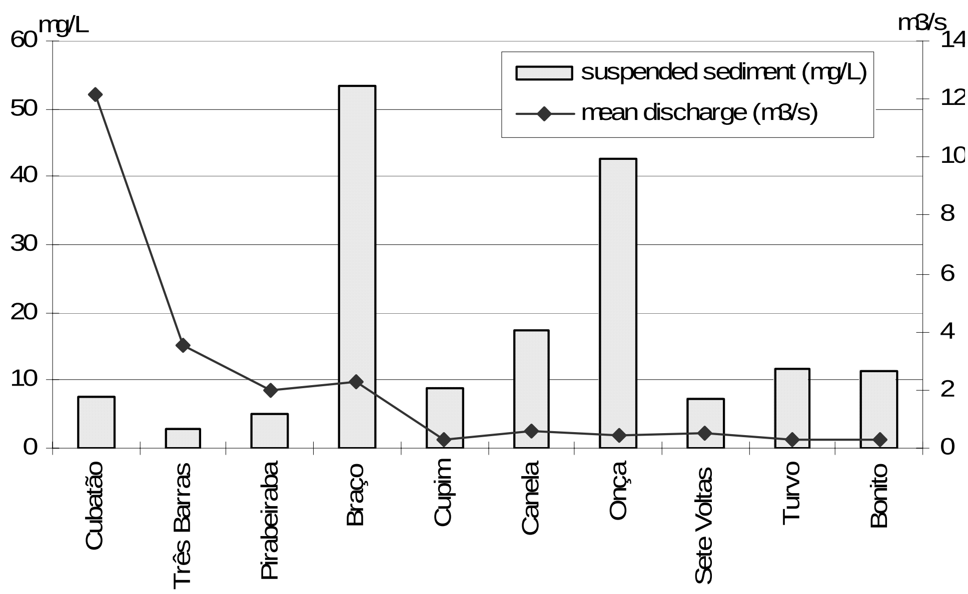

Fig. 2 Mean suspended sediment and discharge values of the studied watersheds. From left to right, watersheds are displayed in size order.

Table 2 Suspended sediment values and discharge/area – area/discharge relations of the studied watersheds. From top to bottom, watersheds are displayed in size order.

River	Suspended sediment (mg/L)	Mean discharge (m^3/s)	Area (km^2)	Discharge/area ($m^3/s/km^2$)	Area/discharge ($km^2/m^3/s$)
Cubatão	7.5	12.14	394.23	0.03	32.48
Três Barras	2.8	3.53	46.85	0.08	13.25
Pirabeiraba	4.9	1.96	40.18	0.05	20.53
Braço	53.5	2.25	36.06	0.06	16.00
Cupim	9.0	0.33	13.10	0.03	39.89
Canela	17.4	0.55	12.90	0.04	23.28
Onça	42.7	0.43	12.70	0.03	29.19
Sete Voltas	7.4	0.48	12.27	0.04	25.54
Turvo	11.6	0.26	10.04	0.03	38.72
Bonito	11.3	0.33	8.27	0.04	25.34

The comparison of specific discharge values (Table 2), shown as discharge/area and area/discharge relations as proposed by Christofoletti (1981), indicates that the largest watershed (Cubatão), together with three much smaller ones (Cupim, Turvo and Onça), present the lowest relation of 0.03 $m^3/s/km^2$, while the second largest (Três Barras) presents the largest relation of 0.08 $m^3/s/km^2$.

The suspended sediment yield into the Babitonga Bay

For the final calculation of the suspended sediment yield into the bay, the mean discharge and sediment values of all watersheds were annualized to obtain rates as tons per year (t/year). The main individual contributor of suspended sediment to the Babitonga Bay is the River Cubatão, with 2789 t/year, followed by the Braço (2789 t/year). The third major contributor is the Onça (517 t/year), followed by the Três Barras (266 t/year), Pirabeiraba (263 t/year) and Canela (260 t/year).

The annual variation of suspended sediment load is usually concentrated in a small number of significant rainfall events, as verified by Droux *et al.* (2003), Schmidt & Frühauf (2000), Schütt (1994) and Hossain & Eyre (2002), among others, in distinct watersheds and environmental conditions. Such events were not monitored in the present study; hence, the suspended-sediment yield values for events may be much higher than the calculated mean values.

Considering the parameter watershed area, it is evident that the contributions of the rivers Braço and Onça are related to land use; both contain large urban areas. Hence, land use seems to be the most significant parameter to consider for environmental planning in the Babitonga Bay area.

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