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Balance de sólidos en suspensión en la cuenca agroforestal del río Valiñas

Suspended sediments yield in the Valiñas agroforestry catchment

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Abstract

Analysis of sediment discharge is considered one of the most objective methods for evaluating erosion intensity. As a part of a project on water quality, a survey of suspended sediments yield and erosion rates was carried out at a small agroforestry catchment of Valiñas River, in the Atlantic area of Spain. Rates of suspended sediment were assessed during six years, from 1999 to 2004. Soils are mainly sandy-loam textured. Land use was 45% forest and 55% agricultural. Yearly rainfall ranged from 786.1 to 1451.5 mm. Water samples were taken during base flow and storm flow conditions. Mean suspended solid concentrations over the six year study period were 30.25 mg/l and the yearly figures varied from 13.67 to 91.12 mg/l. Taking individual samples into account, a maximum of 1044 mg/l of suspended solids was recorded during stormflow, whereas base flow figures were even below 1 mg/l. Patterns of suspended sediment transport at the catchment outlet presented similarities with previous studies in temperate humid regions. Mean annual values of specific sediment yield at the catchment outlet were between 0.066 and 0.574 t/ha/year, indicating a limited availability of sediments for erosion. Low erosion rates during 2004 were caused by the extreme dryness of this year. The largest cause of interannual sediment yields was total discharge.

Key words: suspended solids, erosion, stormflow, sediment yield, water discharge.

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INTRODUCTION

Erosion can be defined as the process of disgregation and transport of soil particles by erosion agents (water, wind) and their posterior sedimentation. Erosion is the main source of diffuse contamination caused by mankind. Its larger effect is observed in agricultural lands (PORTA *et al.,* 2003).

In Atlantic climate regions, soil losses caused by erosion, due to their low magnitude, do not suppose a problem from the viewpoint of soil conservation (VALCÁRCEL ARMESTO *et al.,* 2003) but they can cause phosphorus losses sufficiently high to originate eutrophication (SHARPLEY & REKOLAINEN, 1997; HEATHWAITE, 1997), so the necessity to adopt measurements for minimizing soil and nutrient losses in agricultural lands is admitted.

Moreover, the importance of carrying out a dense sampling for obtaining precise estimations of phosphorus and sediment exportation has been demonstrated (DORIOZ *et al.,* 1989; KRONVANG *et al.,* 1995; VAGSTAD *et al.,* 1996). The main difficulty for obtaining a precise balance of exported phosphorus at catchment scale is the dynamics of this element and the relation between its concentration and the flow.

The objectives of this paper are to measure the suspended solid contents during several years at catchment scale and to relate these contents with soil losses.

MATERIAL AND METHODS

The study was carried out in Valiñas River catchment (36.3 km^2) located at A Coruña province (NW Spain). This land was dedicated to forest (45%), cultures in rotation (35%, maize in rotation with winter cereal) and grassland (20%). Granodiorite was the material of origin for most of the study area; however, basic schists from Ordenes series are represented in a small portion of the area as well. The soil characteristics oscillated between 39.48 and 70.14% sand, 17.25 and 39.51% silt, 11.73 and 21.81% clay, pH(H_2O) from 4.4 to 6.1, 1.6-8.96% total organic C and 0.16-0.64% total organic N (SANDE FOUZ, 2005).

Samples were taken at the outlet of the catchment from January 1999 to December 2004. The number of samples varied from one year to another because of the different rainfall frequency and magnitude among years (Table 1).

YEAR	SAMPLES	RAINFALL (mm)
1999	53	1253
2000	175	1451.5
2001	131	1115.9
2002	78	1218.2
2003	193	1200.3
2004	113	786.1

Table 1. Number of samples and total rainfall per year.

Suspended solid contents were measured using the filtration at 0.45 mm method. Furthermore, the temporal evolution of these contents was studied for this period. Water samples were taken at the outlet of the catchment during base and stormflow conditions. Finally, suspended solid balance was studied at event, monthly and annual scales during the study period. In order to achieve this purpose, suspended solid contents and daily flow data during these years were analyzed using HEC-RAS 3.1 software (US CORP OF ENGINEERS, 2003). HEC-RAS software could be calibrated with periodical gauging performed during 1999 and 2004. Finally, suspended solid balance was studied from the available flow and concentration data at the measurement station. Daily flow data were obtained from gauging experimental measurements in the successive seasons of the year and by interpolation with HEC-RAS software (US CORP OF ENGINEERS, 2003) using the rainfall measured at the Alvedro airport, located at 3 km from the catchment outlet as an auxiliary variable.

Calculations for obtaining the balance were performed at three scales: annual, monthly and during individual events. For annual scale, mean flows and concentrations for each year were used. For monthly scale, monthly flow and concentration means were used. For event scale, balance was performed using every single data of concentration which have been measured experimentally; in this case, flow associated to each concentration was obtained by interpolation assuming that it was constant during the time period which sampling was referred to.

Monthly mean flow evolution during the hydrologic years 1999-2004 is shown in Figure 1. Four out of the five years presented similar characteristics between October and December, the exception was the hydrologic year 2001-2002. Taking into account that the flow data are showed in semilogarithmic scale, in October, mean flows lower than 800 l/s are observed, which increase till figures higher than 2000 l/s in November during all the studied years but 2001; in December mean flows tended to increase except in year 2001-2002.

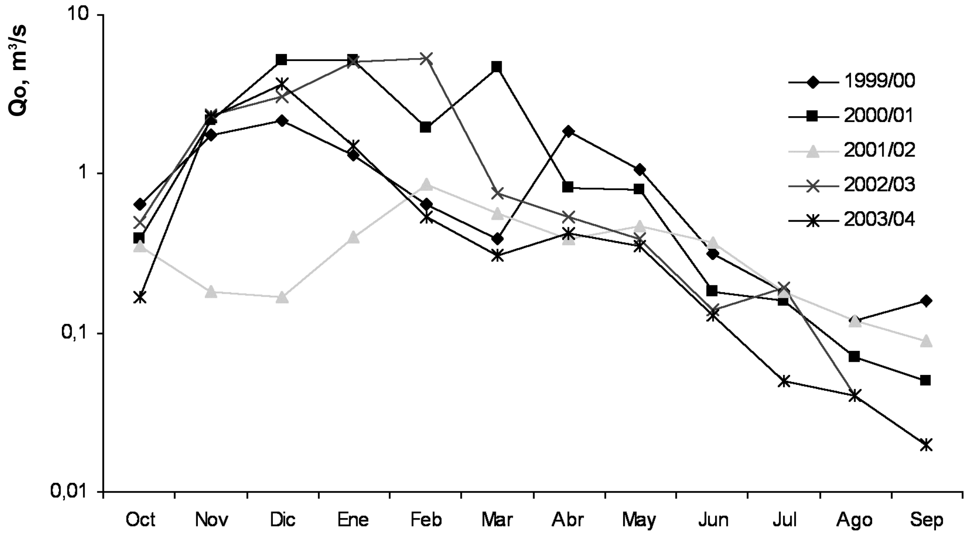

Fig. 1. Flow main characteristics for the hydrological years 1999-2004.

Figure 1 shows that flow values between January and April presented a high variability with important interannual differences, in particular in February and March, flow during humid years can be ten times higher than in dry years. Mean flow decreases regularly between May and September; minimum values tended to occur in September.

Rainfall and monthly mean flow between January 1999 and December 2004 are compared using the natural year as representation unit in Figure 2. Generally, important anomalies related to a regular year are observed during the studied period. Monthly rainfall scale for these values oscillated between 0 and 6000 l/s in 1999, 2000, 2001, 2002 and 2003 and between 0 and 2000 l/s in 2004.

In all of the studied years a parallelism between monthly rainfall and mean flow is observed except during the autumn when a considerable proportion of the water sheet is used for returning the soil humidity to field capacity.

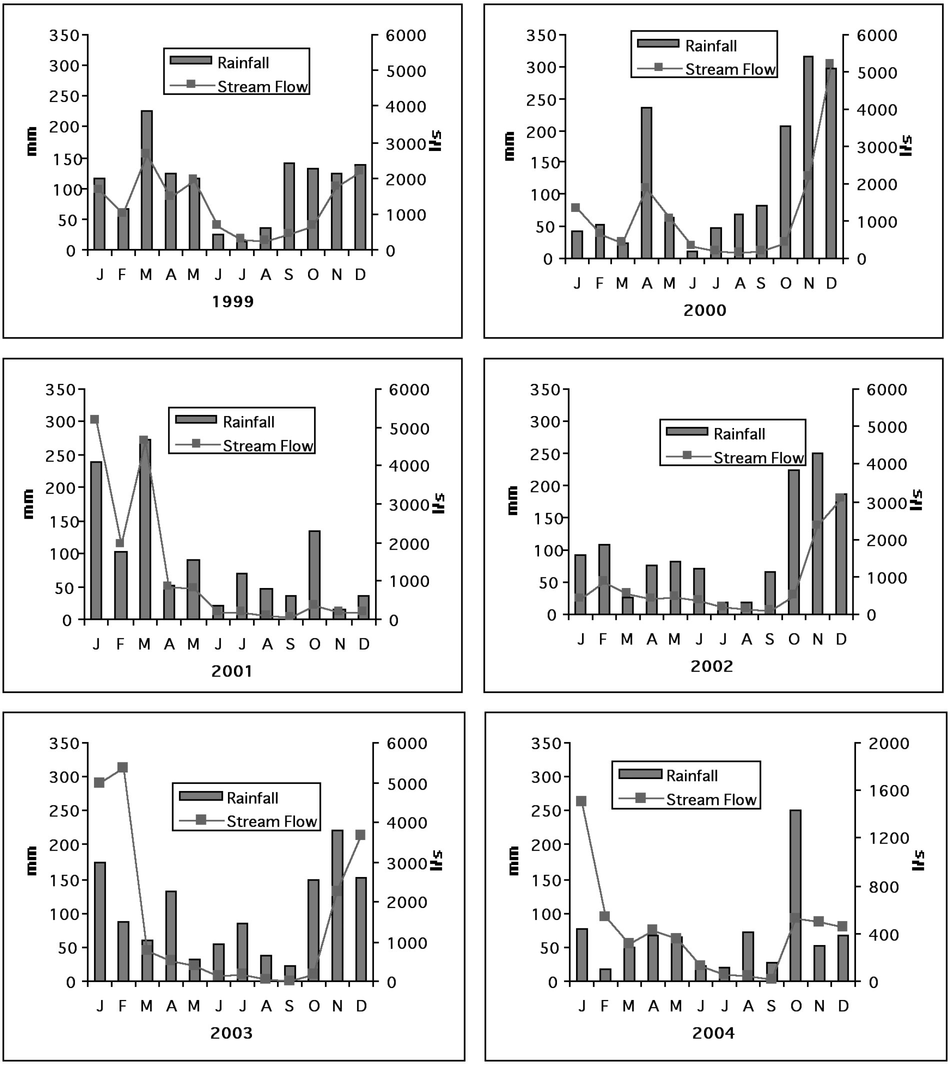

Fig. 2. Mean monthly stream flow and rainfall from 1999 to 2004.

Regarding the humid season, monthly mean flows higher than 4000 l/s were estimated during the extraordinary humid period of 2000-2001 and during the first months of 2003. The fact that the monthly mean flow decreased between May and September was checked even though total rainfall during some summer months can be high.

RESULTS AND DISCUSSION

Suspended solid contents during 1999 to 2004 were studied. Total mean for the six-year period was 30.25 mg/l ranging from 13.67 to 91.12 mg/l for a single year. Table 2 shows the mean, maximum and minimum suspended solid contents and number of samples which are higher than the 100 mg/l threshold.

	Suspended Sediment (mg/l)					
	1999	2000	2001	2002	2003	2004
Mean	30.15	30.9	13.67	91.12	23.93	17.32
Maximum	258	493	99	1044	399	207
Minimum	1	1	1	1	1	1
N>100 mg/l	3	9	0	12	9	4

Table 2. Summary statistics of sediment concentration (N>100 mg/l = samples above this threshold).

Maximum suspended solid content, 1044 mg/l, was observed during a storm flow period in 2002 while 1 mg/l contents were measured during base flow periods (Table 1). Suspended solid contents higher than 100 mg/l were observed in a limited number of samples depending on the year (Table 2).

Furthermore, the evolution of the suspended solid content during the period from 1999 to 2004 was studied (Figures 3-8), and peaks of high suspended solid concentrations were observed. Suspended solid concentration tended to be lower during summertime, namely, from July to September. However, exceptions to this general rule were observed in 2000, minimum for this year was observed during the period from January to March. In 2001, the minimum was observed in the period from October to December. These exceptions were caused by rainfall values lower than the usual ones.

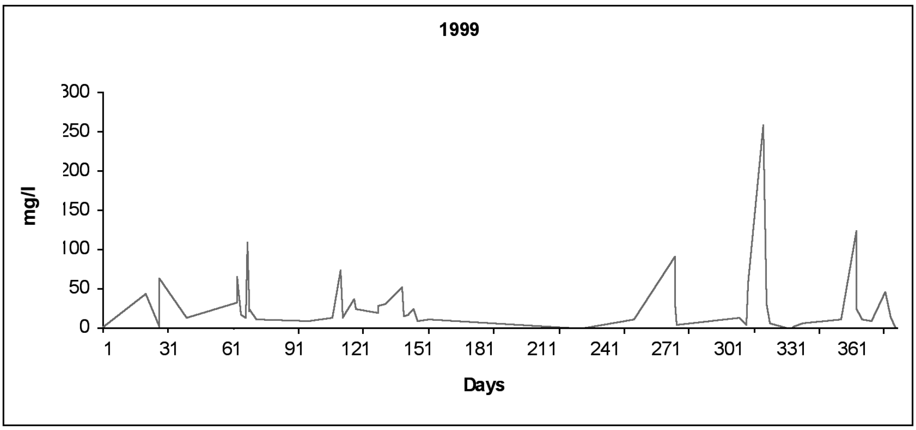

Fig. 3. Yield oscillation of suspended solids during 1999.

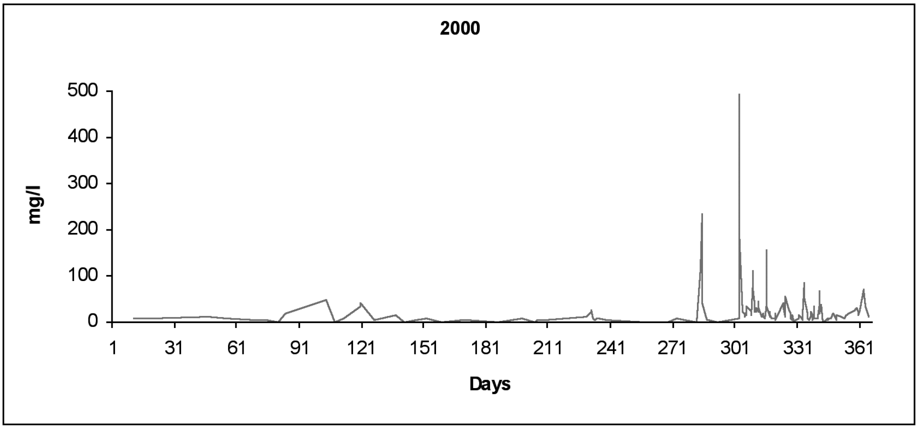

Fig. 4. Yield oscillation of suspended solids during 2000.

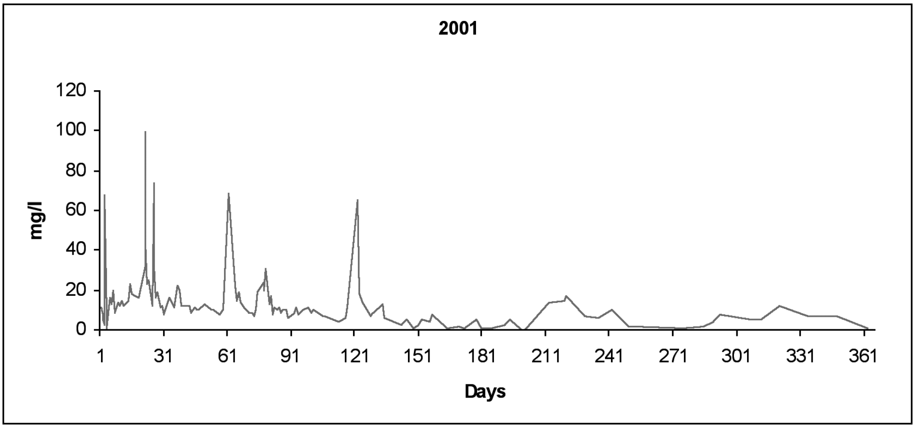

Fig. 5. Yield oscillation of suspended solids during 2001.

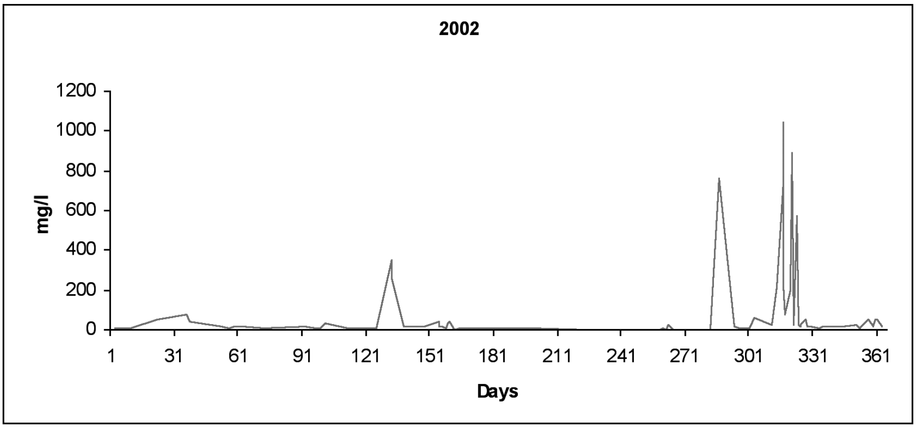

Fig. 6. Yield oscillation of suspended solids during 2002.

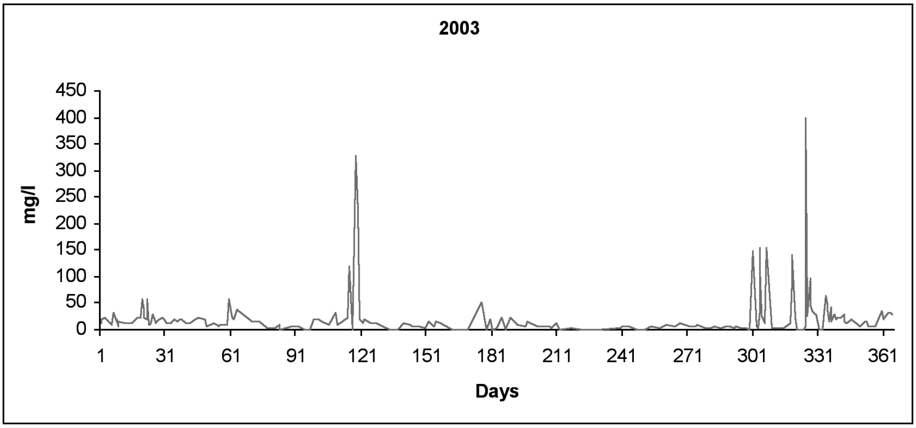

Fig. 7. Yield oscillation of suspended solids during 2003.

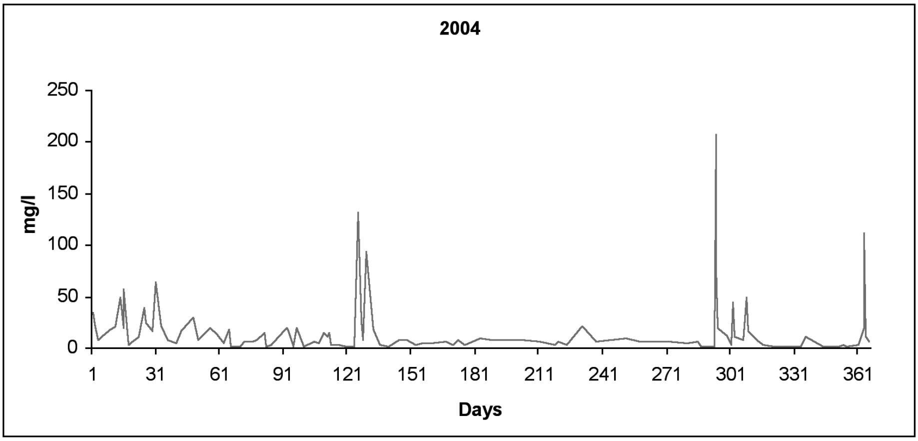

Fig. 8. Yield oscillation of suspended solids during 2004.

Former results showed the influence of the seasonality over suspended solid concentrations. Nevertheless, a cause-effect relation that explained the magnitude of the suspended solid concentrations during a certain season cannot be observed always. This might be due to the fact that high suspended solid concentrations can be related to different factors which, simultaneously, affect to the transfers to aquatic systems. Agricultural soil erosion and runoff, in addition to bank erosion, would cause an increasing of the suspended solids so they must be considered.

Some characteristics of the suspended solid content oscillation can be highlighted in relation with their sources:

Suspended solid peaks are more frequent during spring and autumn when the whole study period is considered. However, high quantities of suspended solids can be registered in any season of the year; moreover, peak inter-annual distribution patterns are very different.

Suspended solids decrease during summertime and, generally, in those periods when there is no rainfall and catchment drainage produces low flows.

Figure 9 shows the relation between suspended sediments and flow in River Valiñas catchment during the six years studied.

Moreover, relations between suspended sediments and flow were studied by gathering data in months. As an example, Figures 10 and 11 show the relation between suspended sediments and flow along April and September 2001 and October 2001 to March 2002.

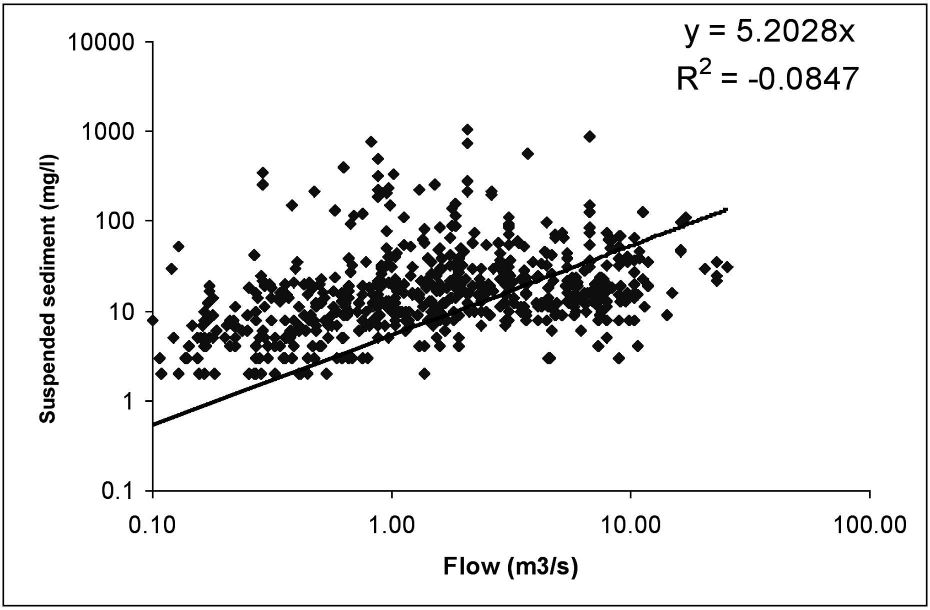

Fig. 9. Relation between suspended sediments and flow.

A high significant correlation ($p<0.01$) between suspended sediments and flow was observed during both time periods, April to September 2001 ($r = 0.778$) and October 2001 to March 2002 ($r = 0.830$).

Furthermore, suspended solid evolution during individual events was studied. Relations between concentration and flow can be negative, indicating that the increasing of the flow is associated with a decreasing of the concentration, and positive, when the flow increasing produces an incorporation of materials to the flux and, therefore, the increasing of their concentration. Regarding suspended solids, hysteresis phenomena are frequent due to the fact that, during floods, suspended solid concentration increased rapidly during the increase stage of the hydrogram so the suspended solid maximum contents are observed before the flow peak is reached. Figure 12 shows an example of relation between concentration and flow during a period of late spring, between 10 and 20 May 1999 and a winter period between 7 and 16 December 1999.

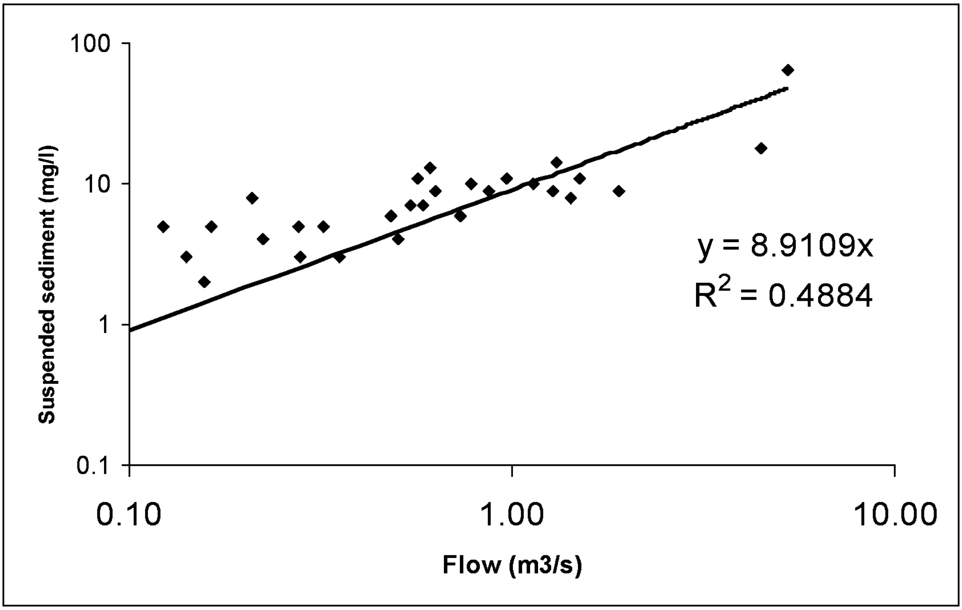

Fig. 10. Relation between suspended sediments and flow during April and September 2001.

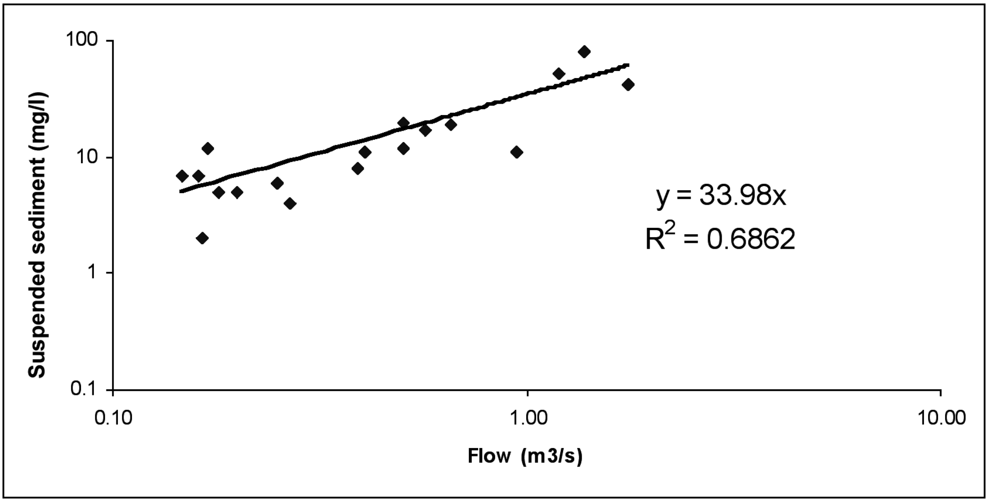

Fig. 11. Relation between suspended sediments and flow during October 2001 and March 2002 in the Valiñas River catchment.

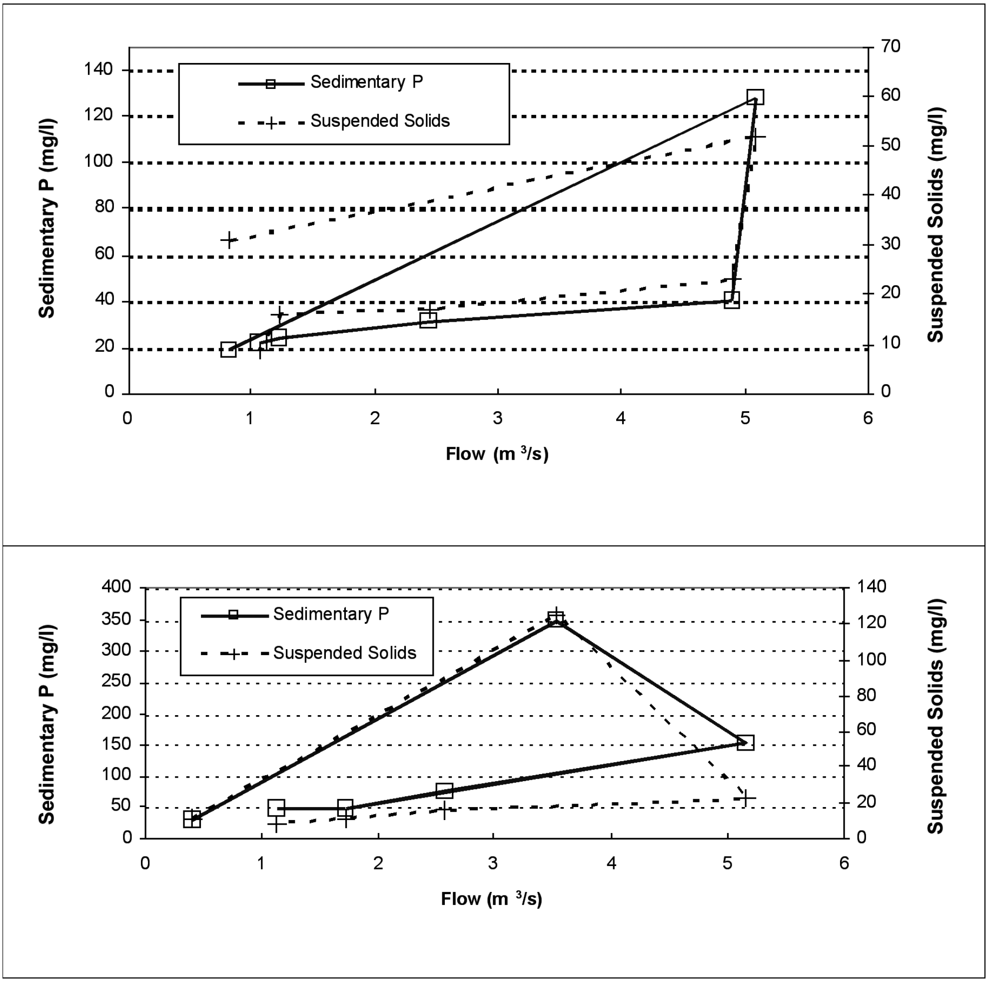

Fig. 12. Suspended solids and flow hysteresis relation during two periods (10 to 20 May 1999 upper side, 7 to 16 December 1999 lower side).

An important hysteresis of the studied variable is observed; its concentration tend to increase rapidly at the very beginning of the ascension of the flow curve and decrease before the maximum flow is reached. The lack of proportionality between flow and concentration is the cause of the difficulty in evaluating the exportation of suspended solids. Hysteresis occurs clockwise. In the first stage, or increasing stage during a storm, suspended solids increase as the discharge (Figure 12) but they begin to decrease rapidly before the peak flow is reached, and they keep on decreasing more rapidly than the flow and tend to reach values of the same magnitude than the measured values in the initial base flow stage; namely, before the event happened. Consequently, when discharge is represented against this variable, clockwise hysteresis loops are observed.

These hysteresis loops have been described by a number of authors under temperate-humid climate conditions (DORIOZ *et al.,* 1989; KRONVANG *et al.,* 1995; STEEGEN *et al.,* 2000). They are caused by a relatively low sediment concentration, so flow is never limitant for the sediment transport; namely, a low increase of the flow is sufficient for transporting suspended solids originated upstream by particle detachment and erosion, once these material has reached the flow from cultural lands.

Suspended solid balance results during 1999 to 2004 are shown in Table 3.

Scale	**Suspended Sediment (mg/l)**					
	1999	**2000**	**2001**	**2002**	**2003**	**2004**
Event	0.303	0.173	0.187	0.574	0.323	0.066
Month	0.326	0.202	0.168	0.600	0.310	0.070
Year	0.322	0.309	0.144	0.617	0.320	0.061

Table 3. Effect of temporal scale on sediment yield balance

When the calculations referred to the three periods are compared, differences in the balance results are not systematic and they can vary depending on the year. Thus, for instance, in 2000 differences between exported suspended solids at annual scale and considering individual periods were 78.6%. In contrast, during 2003 suspended solid figures were less dependent of the period which calculations are referred to.

Results from the literature demonstrated the importance of carrying out more frequent sampling in order to obtain precise estimations of suspended solid exportation (DORIOZ *et al.,* 1989; KRONVANG *et al.,* 1995; VAGSTAD *et al.,* 1996). On the other hand, most of the authors have demonstrated that suspended solids tended to decrease when the time lapse among successive samplings increases. Moreover, the influence of rainfall and flow over the erosion at Valiñas River catchment observed in Table 3 showed that, since the values obtained in 2004, an extremely dry year, were lower than those observed in the rest of the years.

From the export suspended solid quantities in the catchment, an estimation of the mean water erosion can be obtained. At the event scale, export suspended solids from the catchment outlet were 0.303 t/ha in 1999; 0.173 t/ha in 2000; 0.187 t/ha in 2001; 0.574 t/ha in 2002; 0.323 t/ha in 2003 and 0.066 t/ha in 2004 (Table 3).

If it was admitted that the only source of sediments was the water erosion of the cultivated soils, and that erosion intensity in plots dedicated to grassland and forest was practically null and taking into account that cultivated surface was 35% of the catchment, the annual erosion intensities for this soil use would be 0.49 t/ha in 2000; 0.53 t/ha in 2001; 1.64 t/ha in 2002 and 0.92 t/ha in 2003.

These erosion intensities were lower than those obtained in cultivated lands from the schists of Ordenes area that were an average of 2.67 t/ha/year (VALCÁRCEL ARMESTO *et al.,* 2003) during three consecutive years. Valiñas River erosion intensity possessed the same order of magnitude than that obtained in other temperate-humid climate areas with a similar proportion of agricultural land. Due to its low magnitude, it does not suppose a problem from the point of view of soil conservation but can cause phosphorus losses high enough to originate eutrophication risk in surface waters.

Nevertheless, it is necessary to take into account that in Valiñas-like catchments, sediment inputs by bank erosion and, even, flow sediment movilization during floods can contribute in an important way.

Furthermore, it has to be highlighted that a relation between erosion intensity and rainfall or mean annual flow could not be obtained. This lack of parallelism between climatic and hydrologic regime with the sediment production can be a consequence of the necessary interaction between rainfall distribution and the occupation of the soil by a surface without vegetal coberture for occurring erosion. However, non periodical inputs of sediments from bank erosion or building activities contribute to the interannual sediment variability as well.

CONCLUSIONS

Taking into account the total of 743 samples analysed, the mean concentration of suspended solids was 30.25 mg/l. This mean content ranged from 13.67 to 91.12 mg/l depending on the year. The maximum, 1044 mg/l, was observed in 2002 and the minimum was 1 mg/l, observed every year.

In the study period, a limited number of samples higher than 100 mg/l was observed. This number oscillated between 0 and 12 depending on the year.

Annual erosion magnitude in the studied catchment was estimated from suspended solids and flow and it varied from 0.066 to 0.574 t/ha/year. The main source of sediments is the water erosion of cultivated soils and bank erosion.

The importance of the analysed period for estimating exportations of suspended solids was checked. When flow data are available, a very frequent sample is recommended.

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