Temporal variability of suspended sediment transport in a Mediterranean sandy gravel-bed river

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Abstract The temporal variability of suspended sediment transport is investigated in a Mediterranean sandy gravel-bed river (Arbucies, Catalan Coastal Ranges, Spain). Statistical relationships between discharge and suspended sediment concentration from samples obtained every week as well as during flood events during the period 1991-1993, shows a marked scatter of points. This is due to a marked temporal variability of the sediment concentration, caused mainly by: (a) seasonal effects, (b) a progressive exhaustion of sediment available to be transported during sequences of storm events (especially in autumn) and, (c) hysteresis of sediment concentration during individual floods.

INTRODUCTION

Sediment transport and its downstream erosion and sedimentation implications are of increasing interest for water quality and land use management. However, this information is commonly not available in many rivers of Mediterranean regions under different land uses. Information about sediment loads is useful for the evaluation of sediment yield and erosion rates, to describe sediment dynamics during floods and to assess downstream geomorphic effects of the sediment transport. From a technical perspective, this information can be also valuable for planning as well as for various civil engineering purposes.

Since 1991 a research project has been undertaken in the Mediterranean drainage basin of the Arbucies River (Batalla & Sala, 1992; Batalla, 1993). The main aim of this project is to build up a sediment budget emphasizing the contribution of the transport of solid material to the sediment yield. In particular, this paper is focused on the assessment of the temporal variability of the suspended sediment transport in the Arbucies River.

STUDY AREA

The Arbucies River is one of the main tributaries of the Tordera River and is located in the Catalan Coastal Ranges, northeastern part of the Iberian Peninsula, draining an area of 114 km^2. Granodiorite forms the bulk of the plutonic rocks in this region, underlying 75% of the Arbucies catchment area. Quaternary deposits consist of three Holocene terrace levels where sand and fine gravels are predominant. Periglacial processes on hillslopes during the Pleistocene (above 500 m a.s.l.), such as microfracturing, produced important rock disintegration effects. Considerable amounts of sandy material were

released and moved into the streams. The climate of the Arbucies catchment can be classified as humid-Mediterranean, being the seasonal distribution of the precipitation autumn-spring-winter-summer. Mean annual rainfall is 984 mm and mean annual evaporation is 637 mm. Vegetation consists mainly of an evergreen-oak woodland which covers 97% of the basin. An analysis of daily discharges for the period 1967-1992 (Batalla, 1993) shows that there is continuous streamflow for 98% of the time, with an average of 6-7 drought days per year. The mean flow is 1.1 m^3 s^{-1}. Floods can reach 65 m^3 s^{-1} (recurrence interval 50 years). River bed material is mainly poorly sorted sandy gravel with D_{50} equal to 2.2 mm.

DATA COLLECTION

Weekly samples of suspended sediment concentration and discharge measurements, covering a wide range of streamflow conditions and sediment transport rates, were taken at the outlet of the Arbucies River upstream of the gauging station 56. Two-hundred and thirty integrated samples were collected using a US DH48 hand-held depth-integrating sampler. Two samples of 0.5 litres were collected at each sampling. The sampler was lowered to approximately 10 cm from the stream bed to prevent the sampler from touching the bed sediments. In addition, a significant number of samples during floods were obtained by a stage sediment sampler and by the automatic sampler ISCO-3700. Suspended sediment concentrations in mg l^{-1} determined by filtering the sample through 0.45 μm cellulose esters.

RESULTS AND DISCUSSION

The mineralogical composition of the suspended sediment is dominated by sheet-like filosilicated hydroxide of magnesium and biotitic mica, and by different tectosilicates such as quartz and alkaline feldspars.

Mean suspended sediment concentration is 191 mg l^{-1} with a coefficient of variation of 154%. Concentrations vary from 0.7 mg l^{-1} during low flows to 2670 mg l^{-1} during floods. The least squares rating curve relationship (Fig. 1) between discharge (Q in l s^{-1}) and suspended sediment (Q_s in mg l^{-1}) is defined by the statistically significant ($p <$ 0.01) equation:

$$Q_s = 0.0004 \, Q^{1.63} \qquad (r^2 = 0.69) \quad (N = 241) \qquad (1)$$

Statistical bias of the log-transformed least square relation has been corrected by applying the factor developed by Ferguson (1986). The statistical deviation between measured and estimated concentrations has been calculated to be 1.57.

Different authors (e.g. Bogardi, 1974) have suggested that the coefficient (b) and the constant (a) of the statistical relation between discharge (Q) and sediment concentration (Q_s) of the form:

$$Q = aQ_s^b \qquad\qquad (2)$$

can reflect the sediment generating characteristics of the drainage area. Leopold &
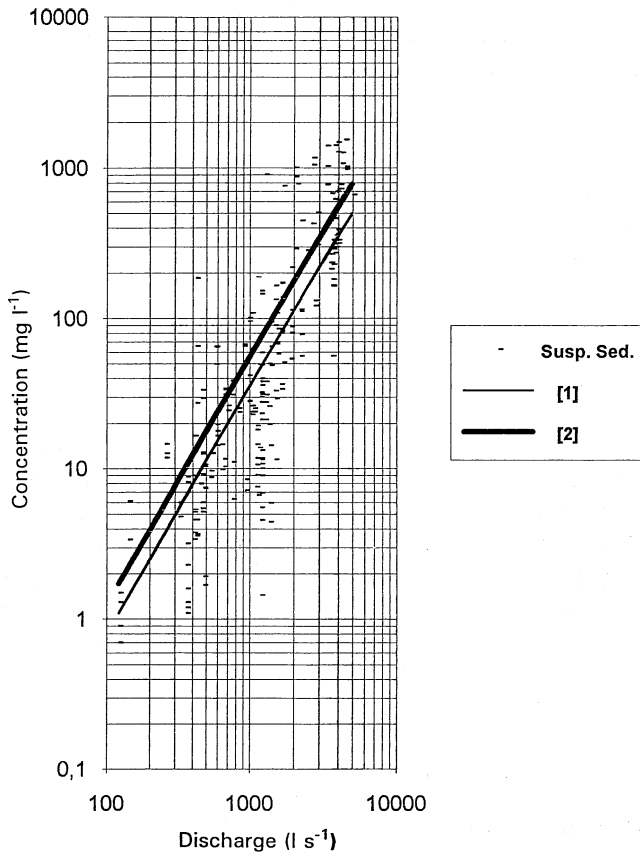
Fig. 1 Least squares relationship (1) and bias corrected (2) rating curve of discharge and suspended sediment concentration of the Arbucies River.

Maddock (1953) showed that the exponent of the statistical relation varied between 2.0 and 3.0. These values were discussed by Gregory & Walling (1973). The intermediate exponent derived from the Arbucies River data ($b = 1.63$) should be associated with a river draining upland catchment developed on resistant rocks.

The scatter associated with the data plotted in Fig. 1 is typical of sediment transport systems (Walling, 1974). This can be explained by (a) seasonal variability of the sediment concentrations (Fig. 2), (b) hysteresis in the discharge-concentration during individual storm events and, (c) progressive exhaustion of sediment supply during a sequence of flood events (Walling & Webb, 1981). In addition, effects of seasonality and storm events on sediment load variability may be maximized in areas under strong seasonal contrast, as occurs in Mediterranean climate-type drainage basins.

Seasonal statistical relations between suspended sediment and discharge have been derived for the Arbucies River in order to assess the degree of correlation (Fig. 3), as suggested by (Hall, 1971; Walling, 1977). The degree of correlation between sediment concentration and discharge increases for spring ($r^2 = 0.78$), summer ($r^2 = 0.85$) and autumn ($r^2 = 0.78$) data, and decreases for the winter relationship ($r^2 = 0.39$). Some interpretations may be made: (a) for any given discharge below 2 m^3 s^{-1}, suspended sediment concentration tends to be lower in autumn than in summer, while above that
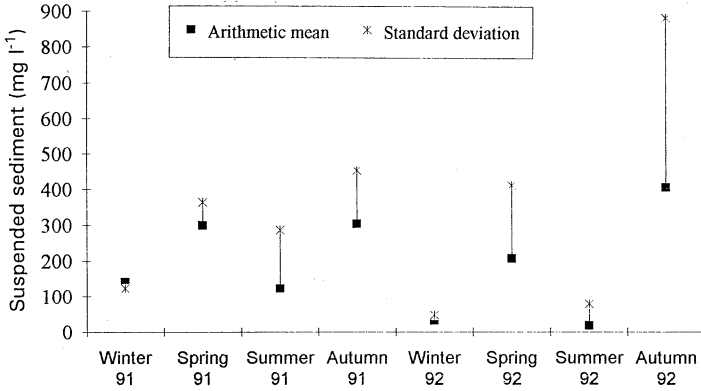
Ramon J. Batalla & Maria Sala

Fig. 2 Seasonal variability of the suspended sediment load in the Arbucies River (1991-1992).

discharge, concentrations tend to be lower in summer than in autumn, (a discharge of 2 m³ s⁻¹ is a small flood event, equalled or exceeded 30 days per year) and, (b) for any given discharge, concentrations tend to be lower in spring rather than in winter. These results provide evidence for the significant role of floods on sediment yield during autumn and spring. The progressive exhaustion of available sediment during sequences
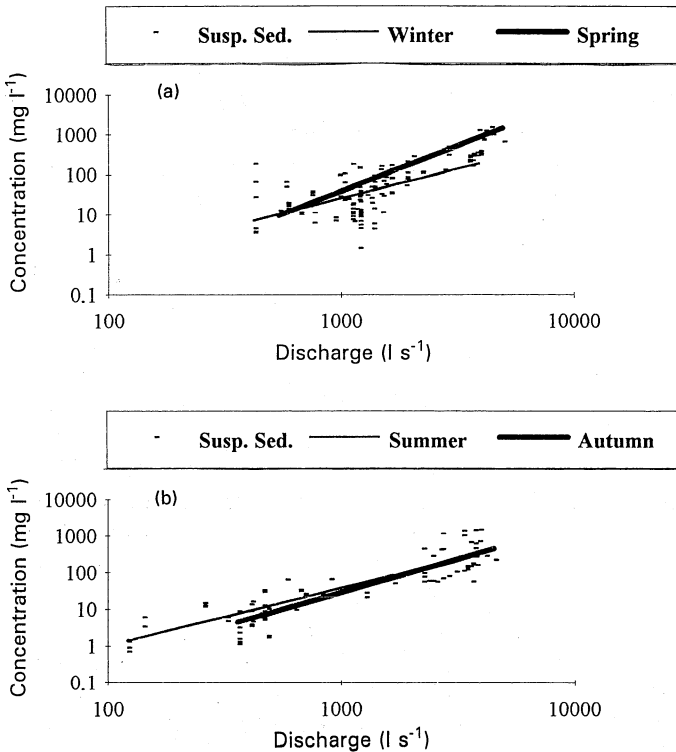

Fig. 3 Seasonal rating curves for discharge and suspended sediment concentrations: (a) winter ($Q_s = 0.001 \, Q^{1.47}$) and spring ($Q_s = 10^{-5.2} \, Q^{2.27}$) and, (b) summer ($Q_s = 0.0007 \, Q^{1.58}$) and autumn ($Q_s = 0.0001 \, Q^{1.82}$), Arbucies River.

Table 1 Decrease of suspended sediment concentration after a sequence of storm events during autumn 1991 and 1992.

	Discharge ($m^3 s^{-1}$)	Suspended sediment (mg l^{-1})
October 1991	0.660	33.0
January 1992	1.350	12.2
October 1992	0.480	10.5
January 1993	0.480	7.5

of storm events has also a marked influence on the sediment load variability. This is especially significant in the winter season after successive floods during autumn (Table 1).

This effect can partly explain the large scatter of points and the high variability of suspended sediment concentrations during the winter months and, thus, the low degree of correlation between discharge and sediment concentration.

The scatter of points between suspended sediment and discharge can also be explained by the variability of concentrations during storm events. The suspended sediment dynamics for the two most important flood events which occurred in the Arbucies River during 1992 and 1993, illustrates this point (Fig. 4). The degree of variability of the sediment concentration during both events is high: the variation between the peak discharge and the falling limb of the hydrograph is higher than 5000% during the first event and approximately 3000% during the second event.

Peak sediment concentration occurred before peak discharge. This phenomenon has been described by different authors (Emmett, 1970; Walling, 1974), and is a common feature of small drainage basins which indicates that the maximum suspended sediment contribution is produced at the beginning of the flood. The sediment concentration begins to decrease while the discharge is still increasing; that is, a clockwise hysteresis is also apparent, especially during the first storm event. For a given discharge, suspended sediment concentrations are higher during the rising limb rather than on the falling limb of the flood hydrograph. For instance, the variation of suspended sediment concentration associated with the same discharge ($2.7 m^3 s^{-1}$) at the beginning and at the end of the first flood was approximately 600%. This phenomenon is perhaps produced by an exhaustion process of the available material in the stream channel. The depleted sediment store could not be rapidly replaced by the sediment contribution either from the slopes (as washed material) or from the headwaters sub-basins.

CONCLUSIONS

The suspended sediment concentration of the Arbucies River exhibits variability due to seasonal effects, exhaustion processes especially during autumn and to sediment behaviour during storm events. Suspended sediment loads are characterized by marked fluctuations in time, being highly sensitive to changes in climatic conditions (i.e. storm events, especially during autumn) which are by no means time constant.
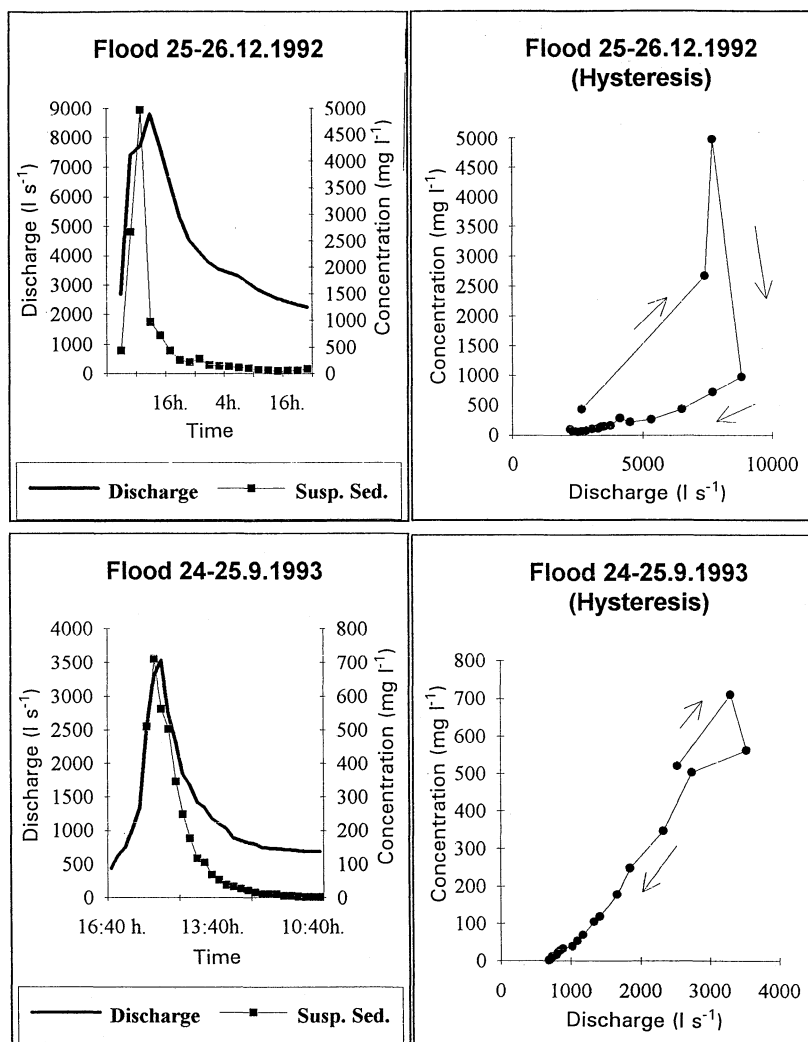
Fig. 4 Sediment dynamics during major floods in the Arbucies River (1992-1993).

The general lack of detailed data on sediment loads is a common situation in many regions of the world. Among other factors this causes considerable difficulties for the assessment of sediment yields, erosion rates, and downstream erosion and deposition implications for sediment transport. This situation is particularly critical in areas with strong seasonal contrasts and rapid land use changes, such as experienced in many Mediterranean regions. Therefore special efforts should be made in the future to improve long term data bases on sediment transport in many of these areas and, subsequently, to develop a better knowledge of temporal and spatial patterns of sediment transport variability.

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