Science of the Total Environment 648 (2019) 33–43

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

An overview of patterns and dynamics of suspended sediment transport in an agroforest headwater system in humid climate: Results from a long-term monitoring

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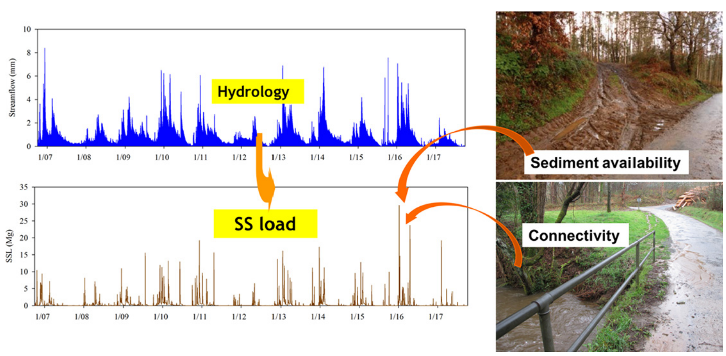
HIGHLIGHTS

- The SS transport dynamic was assessed in a small headwater area in NW Spain.
- The high SS variability underlines the importance of long-term records.
- SS transport is mainly influenced by streamflow; SS availability is also important.
- Multivariate analysis identified the factors controlling the runoff and SS response.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 April 2018
Received in revised form 30 July 2018
Accepted 8 August 2018
Available online 09 August 2018

Keywords:
Suspended sediment transport
Long-term dataset
Headwater catchment
Humid conditions
Multiple regression

ABSTRACT

Small headwater catchments deliver large quantities of suspended sediment (SS) to the ocean. However, there are relatively few studies focused on the study of patterns and dynamics of suspended sediment in headwater catchments over the long-term (10 year or more). In this study, the dynamics of suspended sediment transport were examined at different time scales in a small headwater catchment in NW Spain, based on a 12-year dataset from high-resolution monitoring. The results revealed that, similar to other humid catchments, the hydrological response was highly dependent on initial conditions, especially in autumn and summer. However, in winter and spring the hydrology was more influenced by rainfall amount. The annual suspended sediment was 117 Mg, which equates to a suspended sediment yield of 10 Mg km^{-2} y^{-1}. The SS yield in the Corbeira catchment is related to runoff generation and flooding, which play a key role in sediment yield from the catchment. About 80% of the annual SS was transported over 12% of the study period. Rainfall and discharge at the beginning of the events were the most important factors in explaining the hydrological response at event scale. Suspended sediment transport in this catchment is determined by event magnitude, while the SS is mainly influenced by variables related to runoff erosivity.

1. Introduction

Headwaters are an important resource for biodiversity and human well-being (Lowe and Bishop et al., 2008) mainly because they cover a substantial length of the river course (60–80%; Shreve, 1969), supplying a large proportion of water to

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https://doi.org/10.1016/j.scitotenv.2018.08.118
0048-9697/

downstream reaches (Alexander et al., 2007), providing a buffer for flood risk, and an ecological habitat to preserve the health of the aquatic ecosystems (Meyer et al., 2007). Thus, maintaining the quality of headwater resources is essential for the sustainability of the water environment.

Suspended sediment (SS) transport dynamics in small headwater catchments are determinant factors in the sediment budgets of large river basins, as they contribute a great deal to sediment generation and delivery to downstream reaches (Meybeck et al., 2003; Duvert et al., 2010). In fact, they frequently act as source of sediment because of their steep and deeply morphology (Walling and Webb, 1996; Navratil et al., 2011; Warrick et al., 2015). Therefore, there is a need to provide accurate SS flux estimations within these areas and improve the understanding of the processes governing the sediment generation, transport and deposition in headwater catchments, in order to quantify soil loss and eventually to implement appropriate land conservation practices and reduce sediment delivery to water bodies. Accurate quantification of SS transport requires robust discharge and SS data over long periods (Navratil et al., 2011; García-Ruiz et al., 2015), representative of stationary long-term averages and enabling temporal trends in the increase of concentrations to be observed. It also requires awareness of the short-term fluctuations in SS during rainfall-runoff events, for which capturing high-magnitude and low-frequency events is crucial to ascertain meaningful findings on SS flux (Gallart et al., 2013; García-Ruiz et al., 2015; Grove et al., 2015). Research into SS transport dynamics has focused mainly on a specific temporal scale, i.e. decadal trends in sediment yield (Gao et al., 2015; Raniato et al., 2017) or short-term SS variations during runoff events Rodríguez-Blanco et al., 2010a making it difficult to identify processes and driving factors over multiple timescales (Harvey, 2002; Vercruysse et al., 2017), which are needed for understanding the mechanisms governing sediment transport.

It is widely known that the variability in sediment concentrations is related to the size of the basin, with the watercourses in small catchments being the ones showing the greatest spatial and temporal variability (Vanmaercke et al., 2011; Buendia et al., 2016; Zabaleta et al., 2016). However, research has historically centred on larger basins, so the headwaters have received less attention. Few small rivers have been adequately monitored during major runoff events, due to the difficulty of sampling such short and unforeseen episodes, despite their importance on sediment flux (Sherriff et al., 2015; Nadal-Romero et al., 2018). On the other hand, most of the studies that have dealt with the exploration of the mechanisms responsible for the SS transport in small catchments were carried out in regions affected by high erosion and sediment delivery rates, such as the Mediterranean area or arid and semiarid environments (Duvert et al., 2012; Gallart et al., 2013; Nunes et al., 2016; López-Tarazón and Estrany, 2017; Nadal-Romero et al., 2018). However, so far, very few studies have addressed suspended sediment dynamics and its control factors in the Atlantic region, especially in southern Europe (Milliman and Farnsworth, 2013; Sherriff et al., 2015; Zabaleta et al., 2016) and consequently, little is known about the dominant factors driving SS transport in these areas. This can constitute a challenge because hydrological processes in these areas will probably change in response to climate change, as they are expected to undergo a Mediterranization process. Therefore, the results could provide valuable information for adopting sustainable erosion control measures to improve the management of water catchments in view of climate change.

This research is a continuation of previous studies in rural areas in NW Spain (Rodríguez-Blanco et al., 2010a, 2010b, 2010c; Rodríguez-Blanco et al., 2012; 2013; Palleiro et al., 2014a, 2014b), based on 12-year data set (October 2004–September 2017) collected at high-frequency SS monitoring in a small headwater catchment in NW Spain. Previous studies focused on analysing the hydrology and SS load in the Corbeira catchment, studying relationship between soil erosion and sediment yield, and determining the main SS sources. The scope of these studies is insufficient, since they refer to a small number of rainfall-runoff events and are restricted to short periods of time (4 months–3 hydrological years), preventing the study of intra-annual variability of hydro-sedimentological response, the identification of SS patterns and correct estimation of mean transport rates, for which long-term data (10 years or more) is needed (García-Ruiz et al., 2015).

The aim of this study was to investigate the SS transport dynamics (at different temporal scales) using a long-term data set in order to improve understanding of the hydroclimatic factors and processes controlling SS in small headwater catchments under humid conditions. More precisely, the paper seeks to i) evaluate the inter- and intra-annual variability of streamflow and SS transport; ii) identify control factors in the hydro-sedimentological response of the catchment at the event scale (>350 events) using multivariate statistical tools and iii) test the degree of the prediction by the models at event scale. Data of such quality in this type of environments is rarely available, so it is expected that the results will allow a more detailed and reliable explanation of the factors controlling the SS dynamics in headwater catchments in humid environments, as well as reducing the uncertainty in the estimating of SS yield rates.

2. Materials and methods

2.1. Description of the study area

The study was carried out in the Corbeira catchment (16 km^2), a headwater sub-catchment of the Mero basin (discharging into the Cecebre reservoir) located 30 km northwest of the city of A Coruña in Galicia (NW Spain) (Fig. 1). It is a third-order catchment, with a drainage density of 1.38 km km^{-2}, indicative of the dominance of infiltration on catchment runoff processes, due to permeable soils and the good vegetation cover consisting mainly of commercial eucalyptus and pinus plantations (65% of the catchment) and pastures (26%). The remained area corresponds to cultivated land (4%), mainly maize and winter crop, and impervious areas (5%). The form factor is 0.17, which is considered low and indicative of an elongated catchment. The topography of the area is steep (mean slope of 19%), with slope gradients of >13% in 73% of the catchment and higher than 25% in 25% of the area. The geological substrate is dominated by basic schist of the Órdenes Complex (IGME, 1981) and the most common soil types following the classification of IUSS Working Group WRB (2015) are Umbrisols (75% of the total area), and Cambisols (25%) and are characterised by acid pH (4.5–5.6), silt and silt-loam texture and a high organic content.

The climate in the study area is oceanic, with a long-term mean annual rainfall of 1071 mm (1983/1984–2016/2017). Rainfall occurs throughout the year, although it is concentrated in the autumn and winter seasons, with October, November and December being the rainiest months and July and August the driest ones. In general, there is long, constant precipitation, not usually of high intensity, but causing a large volume of rainwater, although this can vary substantially depending on the type of front to which it is associated. The annual mean temperature is about 13.1 °C, with the lowest monthly historical mean being registered in February (8.6 °C) and highest in July (18.4 °C). The flow regimen is pluvial. In general, high discharge is observed from December to March, falling to low from June to September. Stream flow is low (0.18 m^3 s^{-1}) and mainly supplied by groundwater. The runoff coefficient is about 30%, indicative of a high water-storage capacity of the soils of the catchment. For more information of the study area see Rodríguez-Blanco et al. (2010c, 2012, 2013).

The study catchment is a tributary of the Mero River, the main contributor of water and sediment to the Abegondo-Cecebre reservoir, the only source of drinking water for the city of A Coruña and its metropolitan area, and a Site of Community Importance included in the Nature 2000 network. This reservoir is the only observatory for the international network GLEON (Global Lake Ecological Observatory) on the Iberian