Journal of Environmental Management 194 (2017) 42–53

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Variability in source sediment contributions by applying different statistic test for a Pyrenean catchment

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ARTICLE INFO

Article history:
Received 29 February 2016
Received in revised form
15 July 2016
Accepted 17 July 2016
Available online 3 August 2016

Keywords:
Sediment fingerprinting
Optimum composite fingerprint
Mixing model
Sediment source ascription
Mountain catchment
Spanish Pyrenees

ABSTRACT

Information on sediment contribution and transport dynamics from the contributing catchments is needed to develop management plans to tackle environmental problems related with effects of fine sediment as reservoir siltation. In this respect, the fingerprinting technique is an indirect technique known to be valuable and effective for sediment source identification in river catchments. Large variability in sediment delivery was found in previous studies in the Barasona catchment (1509 km^2, Central Spanish Pyrenees). Simulation results with SWAT and fingerprinting approaches identified badlands and agricultural uses as the main contributors to sediment supply in the reservoir. In this study the <63 μm sediment fraction from the surface reservoir sediments (2 cm) are investigated following the fingerprinting procedure to assess how the use of different statistical procedures affects the amounts of source contributions. Three optimum composite fingerprints were selected to discriminate between source contributions based in land uses/land covers from the same dataset by the application of (1) discriminant function analysis; and its combination (as second step) with (2) Kruskal–Wallis *H*-test and (3) principal components analysis. Source contribution results were different between assessed options with the greatest differences observed for option using #3, including the two step process: principal components analysis and discriminant function analysis. The characteristics of the solutions by the applied mixing model and the conceptual understanding of the catchment showed that the most reliable solution was achieved using #2, the two step process of Kruskal–Wallis *H*-test and discriminant function analysis. The assessment showed the importance of the statistical procedure used to define the optimum composite fingerprint for sediment fingerprinting applications.

1. Introduction

Sediment fingerprinting procedure is employed to identify the primary sediment sources within catchments, to quantify the relative contribution of these sources to the sediment flux and to document the temporal and spatial variability of these source contributions (Walling, 2005; Minella et al., 2008; Collins et al., 2010a, 2010b). Therefore, sediment fingerprinting applications have expanded greatly to support the development of sediment management strategies aimed at dealing with environmental problems associated with erosion and sediment related problems (e.g. Schuller et al., 2013; Tiecher et al., 2015). Together with the expansion in sediment fingerprinting applications it has been an increase in the choices of sediment fingerprinting procedures, often which are tailored to the wide range of potential controls on sediment properties, and the contributions from catchment sediment sources (Walling, 2013). Most sediment fingerprinting approaches involve comparing the properties of samples collected from different target sediments with the properties of potential source areas, such as the surface of different land uses/land covers (e.g. Smith and Blake, 2014; Pulley et al., 2015; Palazón et al., in press).

Sediment source apportionments are quantified based on the identification of differences in the tracer properties or 'fingerprints' of the potential sediment sources on the basis of statistical analysis and interpretation. Although a single sediment property cannot be used to source fingerprinting (Mukundan et al., 2012), it is widely recognized that the inclusion of a combination of several physical and chemical properties incorporated into a composite fingerprint increases the possible level of discrimination and thereby increases the reliability of the relative contribution of those sources (e.g. Walling et al., 1993; Collins and Walling, 2002; Wasson et al., 2002;

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http://dx.doi.org/10.1016/j.jenvman.2016.07.058
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Walling, 2005; Collins et al., 2010a, 2010b). These tracer properties may include geochemical, radionuclide, mineral magnetic, organic constituent, stable isotope and colour properties (Foster and Lees, 2000). While a large number of potential fingerprint properties has been used in sediment fingerprint applications, the need to use statistical tests to confirm the ability of potential fingerprint properties to discriminate between sediment sources and to assist in the selection of the 'best' properties to include in a composite fingerprint became more important and therefore was increasingly recognized.

One of the methodological differences within the range of different applications of the sediment fingerprinting procedure in the literature is related to the statistical analysis used to identify the subset of the tracer properties which 'best' discriminate between sources (Palazón et al., 2015b). Although the two step process outlined by Collins et al. (1997) which combined Kruskal–Wallis *H*-test as first step and discriminant function analysis as second step has been extensively used in source fingerprinting studies (e.g., Russell et al., 2001; Minella et al., 2008; Hughes et al., 2009; Schuller et al., 2013; Stone et al., 2014), other procedures have been used to select the most effective optimum composite fingerprint, such as the use of principal component analysis (e.g. Tiecher et al., 2015). In many cases the use of each statistical process is due to the specific characteristics of the study areas or used fingerprints and, therefore, the selection of the most effective optimum composite fingerprint for each specific application can become time-consuming and complex. Furthermore, previous studies (e.g. Haddadchi et al., 2014; Palazón et al., 2015b) showed that results of the sediment fingerprinting procedure are sensible to different optimum composite fingerprints selected by different statistical procedures pointing to the need for a careful selection of the statistical procedures in each case study.

The importance of the Barasona reservoir, located in the Spanish Pyrenees, as a supplier of water for irrigation to the lowlands and its siltation management problems have been investigated since the 1990s (e.g. Fargas et al., 1997; Avendaño-Salas et al., 1997; Navas et al., 1998; Valero-Garcés et al., 1999). From these studies, those which identified sediment sources pointed to the badlands developed in Eocene marls as the main source of sediment (e.g. López-Tarazón et al., 2015) and some of them also identified agricultural lands as the secondary source of sediments (e.g. Alatorre et al., 2010; Palazón and Navas, 2014, 2016). The study catchment is representative of land use changes that have occurred in the Mediterranean region and which often are cited as primary controls on sediment production (Navas et al., 2008). Our main objective is to assess the variability in source contributions derived by selecting the most reliable optimum composite fingerprints using different statistical procedures. Understanding how statistical operations influence the selection of tracers to discriminate sources is of interest especially for catchments where sediment sources based on land use might not be clearly discriminated because of recent changes in land uses.

2. Material and methods

2.1. Study area

The drainage catchment of the Barasona reservoir is characterised by high relief with an altitude range from 424 to 3404 m a.s.l., a mean elevation of 1313 m and an average catchment slope of 39% (Fig. 1b). The drainage area of the basin studied here is 1509 km^2. The lithological competence of the five main Pyrenean structural units (WNW–ESE-trending geologic units), within the catchment controls the distribution of the geomorphological processes and slope ranges (Palazón and Navas, 2014). These structural units arrange from south to north as follows: the external ranges that delimit the catchment to the south, composed mainly of sandstones and limestones; the intermediate depression, a relative lowland area, composed of detrital sedimentary rocks; the internal ranges composed of large packages of limestones interbedded with marls and sandstones that have developed deep and narrow gorges; the internal depressions (located into the previous structural unit) comprise depressions formed on more erodible materials which develop badlands on marls and the axial Pyrenees composed of quartzites, limestone, shales, granites and granodiorites, with large mountain bodies and the highest Pyrenean peak (Aneto Peak 3404 m a.s.l.).

The catchment has a mountain climate, wet and cold, influenced by the Atlantic Ocean and the Mediterranean Sea (García-Ruiz et al., 2001). The combination of these influences together with the abrupt relief generates gradients in temperature and precipitation as recorded for both north–south and west–east regions. Annual precipitation and temperature range from 500 mm and 12 °C at the outlet (424 m a.s.l.) to more than 2500 mm and less than 4 °C on the highest divides (>3000 m a.s.l.).

The hydrologic regime is transitional nival–pluvial, characterised by two maxima (García-Ruiz et al., 2001): the first due to snowmelt during the spring period (April–June) and the second due to precipitation during late autumn (October–November). Main floods are related with these two maxima and also for localized summer thunderstorms. The Ésera River is regulated by small reservoirs, canals and dams, whereas, the Isábena River is non-regulated.

Forest and pastures occupy more than 50% of the catchment, followed by scrublands (>20%) and cultivated land that occupies around 20% (Fig. 1b). Climatic and topographic gradients from south to north also influence the distribution of the predominating land uses which varied from cultivated lands in the lowland southern areas, to forest in the middle part, to alpine grassland in the highlands. Important changes in land use occurred during the last 60 years in the Spanish Pyrenean region, resulting in substantial agricultural land abandonment to natural reforestation that has affected most parts of the agricultural areas (Navas et al., 2008).

In general, the soils of the catchment are stony and mostly shallow overlying fractured bedrock with textures ranging from loam to sandy loam. Soils are alkaline and generally well-drained with limited average water content and moderate to low structural stability.

The Barasona reservoir, located in the central part of the Spanish Pyrenees, has suffered siltation problems since its construction in 1932 (Navas et al., 1998; Valero-Garcés et al., 1999). A bathymetric survey in 1995 indicated that it had lost one third of its capacity in the first 65 years of operation yielding a specific sediment yield of 3.50 t ha^{-1} year^{-1} (Avendaño-Salas et al., 1997). Siltation rates dated with ^{137}Cs in retrieved sediment cores were high varying between 2 and 18 cm yr^{-1} (Navas et al., 2004) with a general decreasing rate trend after ^{137}Cs maxima (1963) mostly due to stabilisation of land uses changes as recorded in nearby reservoirs (Navas et al., 2009). The majority of the discharge to the reservoir is from the Ésera River catchment and, its main tributary, the Isábena River catchment, which together drainage 1479 km^2 of the catchment. Part of its headwater (30 km^2) is an internal catchment as it drains a karst system (Fig. 1a; Palazón and Navas, 2013).

2.2. Sample collection

A total of 384 individual surface source samples, 4 samples per sampling point, were collected by using a cylindrical core 5 cm long and 6 cm of diameter and combined in the field to form 96 composite samples (83 surface soil and 13 subsoil). Representative sites