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Searching for useful non-systematic tree-ring data sources for flood hazard analysis using GIS tools

J.A. Ballesteros-Cánovas [a,*], A. Díez-Herrero [a], J.M. Bodoque [b]

[a] Department of Research and Geoscientific Prospective, Geological Survey of Spain (IGME), Ríos Rosas 23, Madrid E-28003, Spain
[b] Mining and Geological Engineering Department, University of Castilla-La Mancha, Campus Fábrica de Armas, Avda. Carlos III, Toledo E-45071, Spain

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ABSTRACT

Tree-ring analysis has been demonstrated to be a useful tool for palaeohydrology. Selecting suitable study areas is the first step in palaeoflood research using tree-ring techniques. Objective methods are needed to facilitate exploration and subsequent location of basins where sediment-laden flash floods are likely and that also have tree species suitable for dendrogeomorphological research in a palaeohydrological context.

This paper presents a novel methodology for selecting preliminary suitable watersheds for dendrogeomorphological palaeoflood research in central Spain. Geographical information systems (GIS) provide decision-makers with a powerful set of tools for the manipulation and analysis of spatial information. Using GIS tools and basic thematic maps, we defined three different indexes concerning the occurrence of dendrogeomorphological evidence. A Consensus Decision Making procedure (CDM) was carried out in order to weight each factor individually prior to combining the factors. As a result, we obtained information about the most appropriate watersheds for palaeoflood research using tree-ring analysis. A total of 189 watersheds appeared to be highly interesting for tree-ring studies. Of these only 17 have flow gauges, so data concerning frequency and magnitude of floods in basins without gauges could potentially be provided by dendrogeomorphological studies. In order locate such sites and to carry out such studies more efficiently, a more objective methodology for selecting watersheds for tree-ring studies is presented.

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1. Introduction

Floods in both fluvial and torrential channels are the most damaging hydrological processes and represent one of the major natural hazards worldwide (Gaume et al., 2009; Scheuren et al., 2008; Yalcin and Akyurek, 2004). Floods caused more than US$ 60 billion worth of damage in Europe between 1998 and 2003 (Plate, 2002), either by direct damage to goods and people or consequential damage to the economic development of the affected region following such events. In Spain alone, this natural process was responsible for almost 200 deaths and considerable financial losses over the last twenty years (Ferrer et al., 2004; Pujadas Ferrer, 2002).

Between 1998 and 2004, Europe suffered over 100 major damaging floods, including the catastrophic floods along the Danube and Elbe rivers in summer 2002. Severe floods in 2005 further reinforced the need for concerted action. As a result, the European Commission published the so called Flood Directive (2007/60/EC) on the assessment and management of flood risks in 2007. This Directive obliges Member States to produce hazard and risk flood maps of their territory, especially in areas where hydrometeorological data is scarce and where there may be large uncertainties due to climate change.

Due to the frequent unavailability of systematic and representative data on flood risk, many researchers have recommended the inclusion of non-systematic data, such as sedimentary deposits (Benito and Thorndycraft, 2004; Benito et al., 2009; Livingston et al., 2009) or historical records (Cook, 1987; Payrastre et al., 2005), to obtain probability distributions able to characterise the frequency and magnitude of flooding (Francés, 2004). Botanical evidence is also considered an important indirect data source for flood studies (Baker, 2008). Tree rings provide a valuable and accurate tool since they enable the assessment of the magnitude and frequency of past flash-flood events (Ballesteros Cánovas et al., 2011a, 2011b; Ballesteros et al., 2010a, 2010b; Gottesfeld, 1996; Gottesfeld and Gottesfeld, 1990; McCord, 1996; Ruiz-Villanueva et al., 2010; Yanosky and Jarrett, 2002; Zielonka et al., 2008). Hence, they can be used to draw up hazard maps (Bollschweiler et al., 2008). Despite the existing benefits of using tree ring assessments in palaeohydrology studies (St. George and Nielsen, 2003), the choice of catchment areas where dendrogeomorphological approaches, which it is one of the principles of this discipline (Bodoque, 2007; Cook and Kairiukstis, 1990; Grissino-Mayer, 2011), can be implemented has been based on a preliminary field survey of a specific site where

* Corresponding author.
E-mail addresses: ja.ballesteros@igme.es (J.A. Ballesteros-Cánovas), andres.diez@igme.es (A. Díez-Herrero), jbodoque@geo.ucm.es (J.M. Bodoque).

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there is a clear need to enhance existing data (Stoffel and Bollschweiler, 2008; Wilford et al., 2005a, 2005b). Recently, advanced visual software such as Google Earth® based on aerial photographs and satellite images has been used to help chose potential study sites. However, such a search strategy presents a clear lack of objectivity, which implies several drawbacks that are addressed in the discussion section, especially in large and unexplored or inaccessible territories.

In this study, we present a novel and objective approach based on GIS tools for the preliminary choice of those watersheds in which tree ring techniques could be implemented to improve flood frequency analysis and therefore flood hazard estimation. The methodology described here involved the use of GIS techniques at a large scale in order to integrate processed data from hydrologic and physically based (infinite slope) models, as well as vegetation and geological information. The methodology implemented also includes a decision making process. To ascertain the validity of the results obtained, this search strategy was applied to the central part of Spain (Fig. 1). The aim of this paper is to describe and test a methodology to discriminate those catchments that can be used as dendrogeomorphological data sources for characterising flood hazard in terms of frequency and magnitude.

2. Methodology

An integrated methodology has been developed in order to achieve the stated objective in this paper (Fig. 2). The territorial analysis performed was based on GIS tools and Consensus Decision Making (CDM). It aimed to define a set of variables that determine the degree of existence of dendrogeomorphological evidence along the bars, banks and floodplains of torrential streams at a large scale. In order to evaluate flood intensity, a conceptual hydrologic model as well as a physically based model was used on the catchments contained in the study area. In addition, the suitability of the vegetation for conducting tree-ring studies, as well as the ease of mobilising and incorporating debris in the channel, was also assessed. The methodology requires only basic, easily accessible geographic and thematic data.

2.1. Definition of the flood dendrogeomorphological evidence conditioning indexes

In order to find dendrogeomorphological evidence of floodplains suitable for tree ring studies, a given site must satisfy at least three conditions: i) existence of trees suitable for dendrogeomorphological characterisation and growing on the floodplain; ii) past episodes of low frequency flood events affecting the floodplains; iii) presence in the basin of sediment and debris that can easily enter the drainage network and that can impact trees causing scars.

2.1.1. Index of flash flood severity

Flood hazard is related to the possibility of a river to overflow and inundate the floodplain (Díez-Herrero et al., 2009; Fleming, 2002). The assessment of this index is difficult on a large scale because of the large amount of accurate data required for hydrologic and hydraulic studies. However, the use of GIS tools and the spatial information available in Spain have allowed us to develop an index of flash flood severity. This index is based on the combination of 1) the peak discharge rate obtained with the reference discharge for a given return period (Q_T) and the discharge for a return period of 3 years (Q_b), which is considered in the study area as the bankfull capacity of the stream (Díez-Herrero and Garrote, 2008; Johnson and Heil, 1996; Leopold and Maddock, 1953; Riedel et al., 2005); and 2) the river classification based on the stream slope suggested by Meunier (1989). In this study, Q_T was obtained for a 50 year return period in accordance with the limited longevity of the trees growing on the floodplain.

In order to obtain both peak discharges Q_T and Q_b, a rainfall-runoff method was applied at the study site. The approach implemented consisted of a modification of the Rational method adapted to the specific climatic conditions of Spain (Ferrer, 2003; Rico et al., 2001; Témez, 1991). This method provides peak discharges for

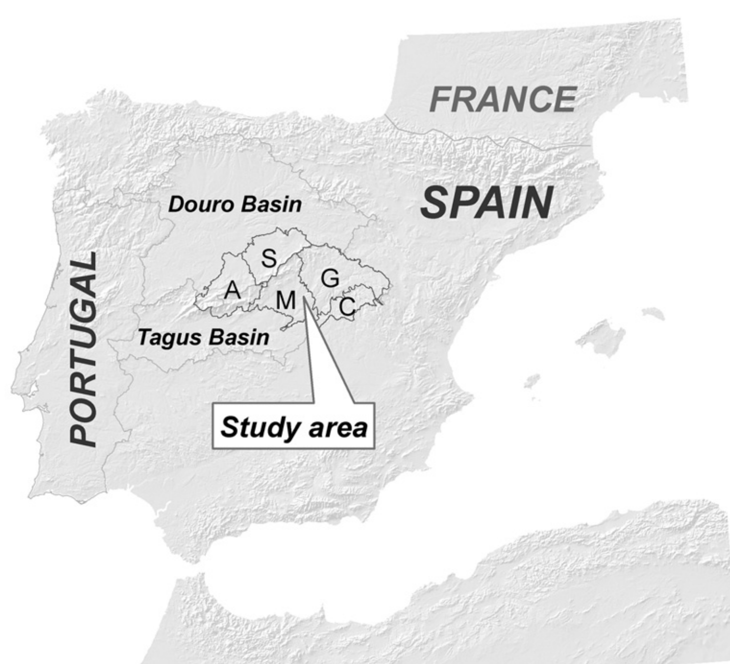

Fig. 1. The study focuses on the Tagus and the Douro watersheds, namely within the territory belonging to the provinces of Segovia (S), Avila (A); Madrid (M); Guadalajara (G) and Cuenca (C).