Science of the Total Environment 511 (2015) 639–648

Contents lists available at ScienceDirect

Science of the Total Environment

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

Flash floods in the Tatra Mountain streams: Frequency and triggers

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HIGHLIGHTS

- Flash floods represent a common natural hazard in the Tatra Mountains.
- Tree ring analysis is the most suitable approach in mountain forested areas.
- We report a flash flood chronology from 4 ungauged catchments covering the last 148 years.
- We identify the common meteorological conditions acting as triggers of flash flood events.

ARTICLE INFO

Article history:
Received 2 November 2014
Received in revised form 22 December 2014
Accepted 22 December 2014
Available online 13 January 2015

Editor: D. Barcelo

Keywords:
Paleohydrology
Dendrogeomorphology
Hydrometeorological triggers
Tatra Mountains
Poland
Norway spruce

ABSTRACT

Flash floods represent a frequently recurring natural phenomenon in the Tatra Mountains. On the northern slopes of the mountain chain, located in Poland, ongoing and expected future changes in climate are thought to further increase the adverse impacts of flash floods. Despite the repeat occurrence of major floods in the densely populated foothills of the Polish Tatras, the headwaters have been characterized by a surprising lack of data, such that any analysis of process variability or hydrometeorological triggers has been largely hampered so far. In this study, dendrogeomorphic techniques have been employed in four poorly-gauged torrential streams of the northern slope of the Tatra Mountains to reconstruct temporal and spatial patterns of past events. Using more than 1100 increment cores of trees injured by past flash floods, we reconstruct 47 events covering the last 148 years and discuss synoptic situations leading to the triggering of flash floods with the existing meteorological and flow gauge data. Tree-ring analyses have allowed highlighting the seasonality of events, providing new insights about potential hydrometeorological triggers as well as a differentiating flash flood activity between catchments. Results of this study could be useful to design future strategies to deal with flash flood risks at the foothills of the Polish Tatras and in the Vistula River catchment.

1. Introduction

Flash floods in mountain catchments are typically localized but highly variable hydrological processes characterized by a large water-sediment discharge in a short time period causing large economic losses and fatalities (Borga et al., 2008, 2014). Their spatio-temporal analysis requires, hence, an accurate definition of rainfall and discharge variables (Tarolli et al., 2012; Viglione et al., 2010). However, the scarcity of instrumental data and basic environmental information in these environments typically leads to considerable uncertainties (Brázdil et al., 2006), hampering our understanding of climate–process linkages and consequently the assessment of existing hazards (de Jong et al., 2009; Merz et al., 2014).

The most accurate alternative to overcome this lack of data in forested mountain catchment is the paleohydrology analysis based on tree-ring data (i.e., dendrogeomorphic methods, Stoffel et al., 2010; Ballesteros-Cánovas et al., in review). Highly-resolved tree-ring records from trees affected by flash floods allow tracking of past process activity with high spatial and temporal accuracy (Stoffel et al., 2006; Schneuwly-Bollschweiler et al., 2012). Over the last decades, the application of dendrogeomorphic analysis in paleohydrology studies has primarily focused on the analysis of flash flood histories at the level of specific catchment (e.g., Astrade and Bégin, 1997; St. George and Nielsen, 2003; Zielonka et al., 2008; Ruiz-Villanueva et al., 2010; Ballesteros-Cánovas et al., in press; Šilhan, 2014), and, in combination with hydraulic models, for the estimation of peak discharge (Yanosky and Jarrett, 2002; Ballesteros-Cánovas et al., 2011a,b). Dendrogeomorphic investigations are also of value at larger scales (Procter et al., 2011; Šilhán, in review), even more so as it is generally recognized that catchments located within homogenous regions may lead to varied hydrological responses. Such

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http://dx.doi.org/10.1016/j.scitotenv.2014.12.081
0048-9697/

physical differences in soil and geomorphology may hinder the transferring of knowledge from one catchment to another even within the same region (Merz and Blöschl, 2005; Blöschl, 2006), thereby limiting the specific understanding of flash flood processes. Beyond the interest of tree-ring analysis in comparative hydrology (Blöschl, 2006), flash flood studies at regional scales also allow a better understanding of the mechanisms that determine the long-term history of these processes in terms of magnitude, frequency, and seasonality — as well as climate–flood linkages at the regional scale (Merz et al., 2014).

Based on the above considerations, we here present a spatio-temporal reconstruction of past flash flood activity in four selected, poorly gauged mountain streams located on the northern slope of the Tatra Mountains (South Poland). Based on the analysis and dating of flood damage in *Picea abies* (L.) Karst. and *Abies alba* Mill.,we reconstruct flash flood occurrence during the last 148 years and provide frequencies of events. Based on the analysis of local meteorological data, we also determine hydrometeorological threshold related with the reconstructed flash flood and discuss the hydrologic behavior of this region during intense rainfall events.

2. Study area

The study was conducted in four streams draining the northern slope of the Tatra Mountains (Tatras), the highest massif of Carpathian arc (max. elevation 2655 m a.s.l.; Fig. 1). The Tatras have a crystalline and metamorphic core covered by nappes of Mesozoic sedimentary rocks. During the Pleistocene, the Tatras underwent at least three glaciations, which strongly reshaped the region, left conspicuous relief forms and typical moraine deposits.

Climate of the Tatras is influenced by regional air mass oscillations and local topography, with a predominance of polar marine (65% of annual incidents) and polar continental airmasses (25%; Niedźwiedź et al., 2014). The Tatras also form a considerable barrier for air mass movements resulting in heavy rainfall events with 24-h sums of up to 300 mm (30 June 1973; Niedźwiedź, 2003). Annual precipitation varies from 1100 mm at the foothills (Zakopane, 844 m a.s.l.) to 1660 mm at timberline (Hala Gąsienicowa, 1550 m a.s.l.) and 1721 mm on the summits (Lomnicky stit, 2635 m a.s.l.). The most effective precipitation events that result in flash floods are largely concentrated to the summer months as shown in Fig. 2.

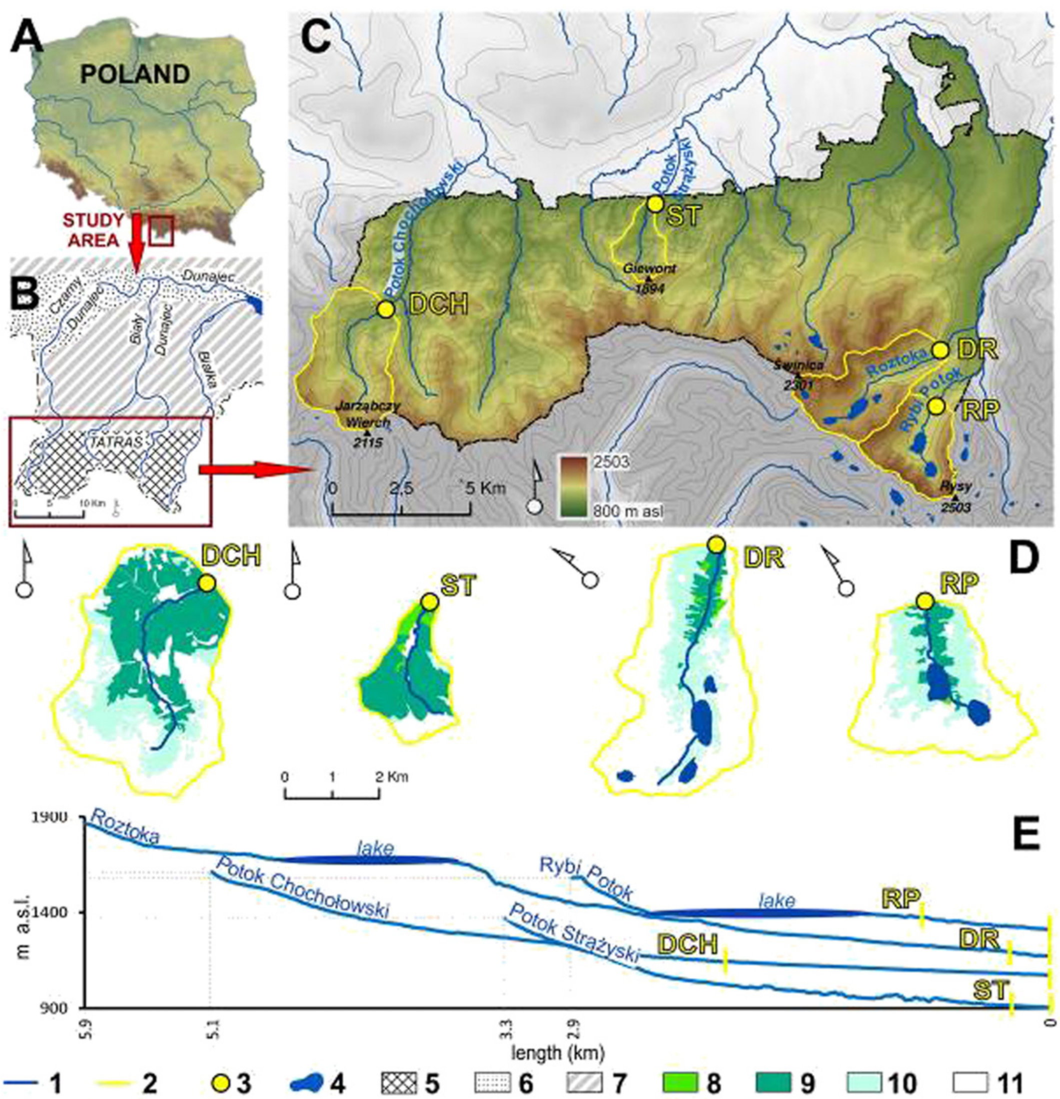

Fig. 1. (A) Location of the study site in Poland. (B) Overview of main rivers draining the Tatra Mountains. (C) Location of the investigated catchments and (D) their land-use characteristics. (E) Altitudinal profiles of the studied streams. Legend: 1 — streams; 2 — investigated catchments; 3 — dendrogeomorphic study sites (RP = Rybi Potok, DR = Dolina Roztoki; DCH = Dolina Chochołowska, ST = Strążyski Potok); 4 — lakes (WSP — Wielki Staw Polski Lake, MO — Morskie Oko Lake); 5 — high mountains; 6 — intramontane and submontane depressions; 7 — mountains of intermediate and low height; 8 — deciduous forest; 9 — coniferous forest; 10 — dwarf pine; 11 — low vegetation.