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Impact of piping on gully development in mid-altitude mountains under a temperate climate: A dendrogeomorphological approach

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A B S T R A C T

Gullies are complex geomorphic systems induced and transformed not only by surface erosion processes, but also by subsurface processes such as piping. However, the transient nature of piping makes this process more difficult to observe and study, especially when a pipe roof has totally collapsed. This study aims at assessing piping impact on gully initiation and development using dendrogeomorphological analyses, which are a novel approach in piping study. The survey was carried out in a mountainous area under a temperate climate, using the Bereźnica Wyżna catchment in the Bieszczady Mts. (Eastern Carpathians) as a case study. We estimated the minimum age of pipe collapses and presented the transformation of pipe collapses in order to identify the direction of pipe and gully development. We also verified the contribution of piping to gully development by the reconstruction of gully bottom deepening. The analysis was based on changes in tree and root wood anatomy in diffuse-porous deciduous angiosperm species, i.e. common alder (*Alnus glutinosa*) and field maple (*Acer campestre*). The pipe collapses in the piping system studied are at least 19 to 23–27 years old and the pipe roof initially collapsed in the lower sections of the slope (above the gully head) and the pipe develops up the slope by headward erosion. The gully that was analysed in forest had been deepened by piping during several episodes connected with high precipitation events. In contrast, the pipe located in grasslands collapsed 1–2 years after such events indicating that dense vegetation delays pipe collapse. This study shows that dendrogeomorphological analyses based on diffuse-porous deciduous angiosperm species may be a useful tool in piping research. It provides information on pipe and gully development, as well as enabling estimates to be made of the age of pipe collapses.

1. Introduction

In past decades, the priority of research has been given to surface processes and overland flow, which are more visible and easier to quantify than subsurface flow, and thus than subsurface erosion. The initiation and development of channel networks have been dominated by the concept of Hortonian overland flow (Bryan and Jones, 1997). Piping was underestimated as a process of mechanical removal of soil particles by concentrated subsurface flow (Boucher, 1990). This slowly changed in the 1960s and 1970s, when the impact of subsurface flow on storm hydrographs was noted and piping began to be seen as a geomorphic phenomenon (Bryan and Jones, 1997). In the 1980s and early 1990s a series of works was published on the role of piping in gully development (Alexander, 1982; Baillie et al., 1986; Bocco, 1991; Bryan and Harvey, 1985; Crouch, 1983; Dunne, 1980, 1990; Gerits et al., 1987; Gilman and Newson, 1980; Harvey, 1982; Imeson and Kwaad, 1980; Jones, 1981, 1987; Parker and Higgins, 1990; Poesen, 1989; Swanson et al., 1989). This research is still continuing, mostly in semi-arid areas with scarce vegetation (Faulkner, 2013; Frankl et al., 2012; Nichols et al., 2016; Vandekerckhove et al., 2003; Zhu, 2003, 2012). There are few papers on the dynamics of piping-origin gullies (e.g. Frankl et al., 2012; Jones, 1968; Nichols et al., 2016; Parker and Higgins, 1990; Poesen et al., 1996; Vandekerckhove et al., 2003; Wilson et al., 2015). Most of these reports are devoted to pastures and grasslands, or even to unvegetated areas. Despite these valuable results, the impact of piping on gully initiation and development requires further study, and piping in forested areas in particular is still being overlooked.

Hitherto research on piping in forested areas was concentrated on the hydrological aspect of pipeflow (e.g. Sayer et al., 2006; Sidle et al., 2001; Terajima et al., 2000; Uchida et al., 1999, 2001, 2005; Wilson et al., 1990) and its relation to landslides (Durgin, 1984; Uchida et al., 2001). There are some reports on gullies induced by piping under forest cover (e.g. Bernatek, 2015; Gergely and Szalai, 2015), but these are rather limited.

Moreover, the great majority of the studies referred to are based on

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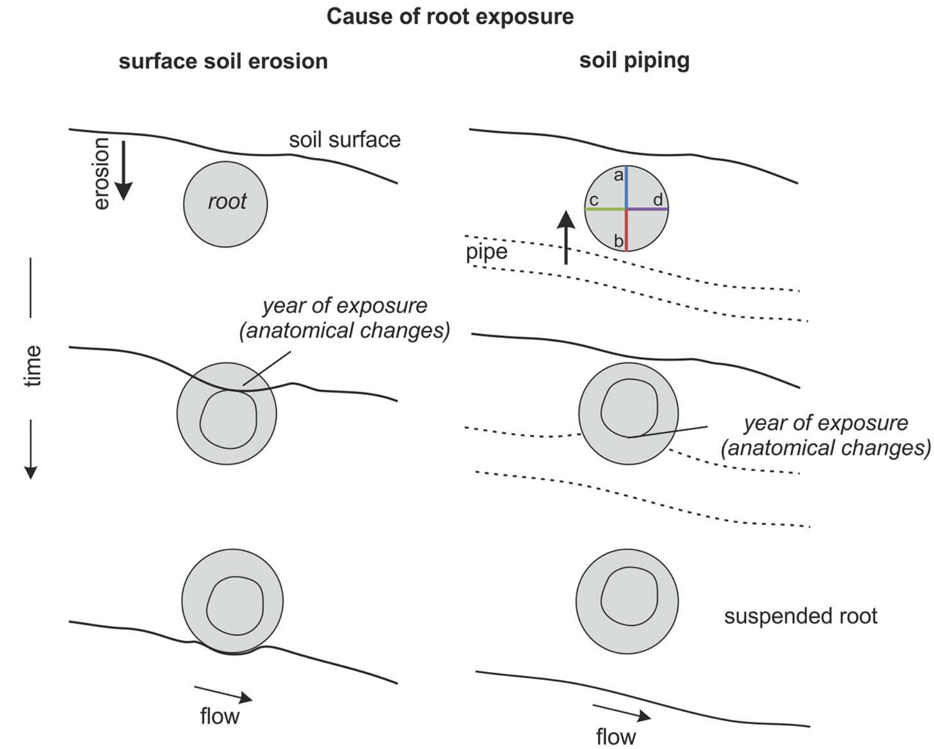

Fig. 1. Root exposure caused by surface and subsurface soil erosion (piping). Letters "a", "b", "c" and "d" indicate the root cross-sections (CS) in four different radii, within which the wood anatomical measurements were performed: "a" – upper side of root CS, "b" – lower side of root CS, "c" – upslope side of root CS, and "d" – downslope side of root CS.

geomorphological mapping of collapsed pipes (CPs). This method is useful in all types of region, both those with sparse vegetation (such as badlands in a semi-arid climate; e.g. Chilton et al., 2008; Zhu, 2003) and those with dense vegetation (such as grasslands in a temperate climate; e.g. Bernatek, 2015; Verachtert et al., 2010; Wilson et al., 2015; Zhang and Wilson, 2013). However, it is limited to surface indicators of piping (i.e. collapsed pipes) and may lead to an underestimation of piping, which occurs under the surface (Bernatek-Jakiel and Kondracka, 2016; Got et al., 2014; Holden et al., 2002). Furthermore, it is constrained to a relatively short time period. To the best of our knowledge, the longest period of measurement of pipe development was 12 years in the Loess Plateau in China (Zhu, 2003), and 45 years in the Bieszczady Mountains in Poland (Bernatek-Jakiel et al., 2017a). It seems that dendrogeomorphology can provide more information on the impact of piping on gully initiation and gully development.

Dendrogeomorphology (Alestalo, 1971) uses plant ecology and dendrochronology to study geomorphological processes from both the spatial and temporal standpoints. It is based on the so-called process–event–response system defined by Shroder (1980) in that geomorphological processes cause specific events to occur in the vicinity of a tree which lead to a response in it, such as growth variations or anatomical/morphological changes in tree rings and roots. Dendrogeomorphological analyses allow one to date these disturbances induced by geomorphological processes. For instance, processes affecting tree growth can be reflected in variations in the width of growth rings, growth suppression or release, reaction wood, wounding and scar occurrence. Dendrogeomorphological methods are currently used to reconstruct a variety of geomorphological processes, such as landslides (Bollati et al., 2016; Corominas and Moya, 1999; Migoń et al., 2010, 2014; Wrońska-Wałach et al., 2014), floods (Ballesteros et al., 2010b; Zielonka et al., 2008), rockfall activity (Schneuwly and Stoffel, 2008; Trappmann and Stoffel, 2015), debris flow and avalanches (Malik and Owczarek, 2009; Šilhán and Tichavský, 2016; Wrońska-Wałach, 2014), sheet erosion (Bodoque et al., 2005, 2011; Rubiales et al., 2008), gully erosion (Vandekerckhove et al., 2001; Wrońska-Wałach, 2014), and soil erosion (Gärtner et al., 2001; Hitz et al., 2006, 2008; Stoffel et al., 2013). Recently, Bollati et al. (2012) reported results concerning the impact of piping on slope stability based on the persistence of compression wood in trees. Moreover, they found erosion rates, in correspondence of suspect piping that are lower than in the neighbourhood areas where superficial runoff prevails (Bollati et al., 2012).

The dendrogeomorphological approach has been used to study gully development, mainly through gully erosion and the assessment of erosion rates due to sheet erosion in the gully bottom (e.g. Ballesteros-Cánovas et al., 2017; Bodoque et al., 2011; Chartier et al., 2016; Malik, 2008; Šilhán, 2012; Šilhán et al., 2016; Wrońska-Wałach, 2014; Vandekerckhove et al., 2001, 2003). In this instance root exposure was being assessed and one of the most common visible changes after root exposure was eccentric ring growth (Ballesteros-Cánovas et al., 2013). Sometimes abrasion scars of cambium tissues can also be detected (Ballesteros et al., 2010a, 2010b; Schneuwly et al., 2009). However, due to the difficulty in differentiating the growth rings in roots (Fayle, 1968; Gärtner et al., 2001) changes to wood anatomy are crucial in analyses of root exposure (Ballesteros-Cánovas et al., 2013). The main changes are related to increasing growth ring thickness due to a greater number of cells in earlywood (EW) (Ballesteros-Cánovas et al., 2013), reduction in the lumen area of EW tracheids, and an increased cell wall thickness of latewood (LW) tracheids (Bodoque et al., 2005, 2011; Carrara and Carroll, 1979; Chartier et al., 2016). However, most research has been conducted in coniferous trees (e.g. Bodoque et al., 2005; Gärtner et al., 2001; Rubiales et al., 2008; Wrońska-Wałach, 2014), whereas analyses of broadleaved species are limited and based mainly on vessel lumen size (e.g. Chartier et al., 2016; Hitz et al., 2008; Šilhán et al., 2016). Moreover, most research is devoted to surface gully erosion, whereas gullies are complex geomorphic systems which are also induced and transformed by piping and mass movements (De Ploey and Poesen, 1987; Poesen, 1993; Starkel, 2011).

It seems that the impact of piping on gully development may be assessed using a dendrogeomorphological analysis, as piping affects roots by exposing them starting from the lower side of root (in the pipe