Geomorphology 192 (2013) 1–14

Contents lists available at SciVerse ScienceDirect

Geomorphology

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

Impact of soil characteristics and land use on pipe erosion in a temperate humid climate: Field studies in Belgium

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ARTICLE INFO

Article history:
Received 18 May 2012
Received in revised form 18 November 2012
Accepted 25 February 2013
Available online 4 March 2013

Keywords:
Soil piping
Subsurface erosion
Biological activity
Earthworm
Abiotic soil characteristics

ABSTRACT

This study investigates the role of soil characteristics and land use in the development of soil pipes in the loess belt of Belgium. First, we tested the hypothesis that discontinuities in the soil profile enhance lateral flow and piping by impeding vertical infiltration. We focus on discontinuities in soil characteristics that can vary with soil depth, including texture, saturated hydraulic conductivity, penetration resistance, and bulk density. These characteristics as well as soil biological activity were studied in detail on 12 representative soil profiles for different land use types. Twelve sites were selected in the Flemish Ardennes (Belgium): four pastures with collapsed pipes (CP), four pastures without CP, two sites under arable land without CP and two sites under forest without CP. Secondly, this study aimed at evaluating the interaction of groundwater table positions (through soil augerings) and CP in a larger area, with a focus on pastures. Pasture is the land use where almost all CP in the study area are observed. Therefore, the position of the groundwater table was compared for 15 pastures with CP and 14 pastures without CP, having comparable topographical characteristics in terms of slope gradient and contributing area. Finally, the effect of land use history on the occurrence of pipe collapse was evaluated for a database of 84 parcels with CP and 84 parcels without CP, currently under pasture. As to the first hypothesis, no clear discontinuities for abiotic soil characteristics in soil profiles were observed at the depth where pipes occur, but pastures with CP had significantly more earthworm channels and mole burrows at larger depths (>120 cm: mean of >200 earthworm channels per m^2) than pastures without CP, arable land or forest (>120 cm depth, a few or no earthworm channels left). The land use history appeared to be similar for the pastures with and without CP. Combining all results from soil profiles and soil augering indicates that intense biological activity (especially by earthworms and moles), in combination with a sufficiently high groundwater table, favours the development of soil pipes in the study area.

1. Introduction

Soil piping or tunnel erosion refers to the formation of linear voids by concentrated flowing water in soils or unconsolidated sediments, which can cause topsoil collapse and the formation of discontinuous gullies (Jones, 2004). Piping has been associated primarily with semi-arid environments, yet piping is considered to be a critically important soil erosion process in many climatic regions (Jones, 1971; Faulkner, 2006). Although topographical variables (sufficient hydraulic gradient, contributing area, curvature) influence pipe development, the subsurface pipe network may owe more to in-profile variations than to surface topography (Jones, 1997). In the semi-arid environments of Europe, the dispersion of the material and its geochemical properties has been found to play roles alongside site hydrology. In the humid-temperate context of the loessic environments of northern Europe, however, geochemistry is assumed to be irrelevant to pipe initiation. Instead, piping is usually argued to be associated with discontinuities in physical composition (Faulkner, 2006). Preferred locations for pipes are just above or within a horizon of low relative permeability (Fletcher et al., 1954; Jones, 1971) and low aggregate stability (Jones, 1971; Botschek et al., 2002a). For dispersive soils, it has been often reported that pipes typically occur at significant subsurface textural discontinuities in duplex soils, which can be explained by differential swelling and shrinking, resulting from differences in clay content and clay minerals with depth (Imeson and Kwaad, 1980; López-Bermúdez and Romero-Díaz, 1989). For collapsible loess, an argillic horizon may

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0169-555X/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.geomorph.2013.02.019

produce a similar 'duplex' character (Faulkner, 2006). Unfortunately, literature about piping in loess-derived soils in a temperate humid climate is limited, with a few exceptions (Botschek et al., 2002a,b; Bíl and Kubeček, 2012).

Piping may be further enhanced by macropores, which can result from desiccation cracks (Hughes, 1972; Jones et al., 1997; Farifteh and Soeters, 1999), tectonic joints (Benito et al., 1993; Farifteh and Soeters, 1999), root channels or animal burrows. Some studies reported that animal burrows were important for piping, as they are effective preferential flow paths providing the necessary pipe flow discharge and subsurface erosion (Carroll, 1949; Czeppe, 1960; Hosking, 1967 cited in Baillie, 1975; Jones, 1981 cited in Jones, 1981; Farres et al., 1990; Pickard, 1999; Botschek et al., 2002b). Others reported that burrowing animals are only a minor factor influencing pipe development (Fletcher and Carroll, 1948); i.e. they can create inlets for water, but they are not necessary for soil piping.

An inventory of 137 parcels (farmer's plots) with 560 collapsed pipes (CP) in the Flemish Ardennes (Belgium; study area of 236 km^2; Fig. 1) revealed that zones with soil profiles developed on loess covering homogeneous massive clays (Tertiary, Aalbeke Member) are most prone to pipe collapse (Verachtert et al., 2010). Furthermore, land use plays an important role, as 97% of parcels with CP were found under pasture. Previous studies suggest that a discontinuity in soil characteristics in the soil profile can play an important role in pipe development. Therefore, the first objective of this study is to investigate the presence of discontinuities in soil characteristics for soil profiles with and without CP in the loess-derived soils of the Flemish Ardennes (Belgium). Twelve soil profiles were selected to represent different land uses (pasture, cropland and forest) in comparable geological and topographical contexts. Soil characteristics evaluated in the profiles included physical characteristics (penetration resistance, bulk density, saturated hydraulic conductivity K_{sat} and texture), biological activity (earthworm channel density and presence of mole burrows) and groundwater table depths. In order to evaluate the interaction of the groundwater table positions and CP in a larger area than could be studied by soil profile pits, additional augerings were conducted to determine the position of the groundwater table in 15 pastures with and 14 pastures without CP. The aim was to investigate if the groundwater table depth, the soil depth range over which the water fluctuates throughout the year and the Tertiary substrate differ between pastures with and without CP. Finally, assuming that biological activity is important for pipe formation, it is likely that a transition period is needed before biological activity, induced by conversion to pasture, has sufficiently developed to induce piping after land use change. Therefore, the land use history of parcels with CP was compared with that of parcels without CP.

Summarizing, the main objectives of this study are: (i) to determine if discontinuities in abiotic soil characteristics or biological activity occur at depths where pipes occur, and thus enhance lateral flow and pipe development, (ii) to investigate if groundwater table positions and depth of the Tertiary substrate differ significantly between pastures with and without CP, and (iii) to investigate whether land use history affects CP development.

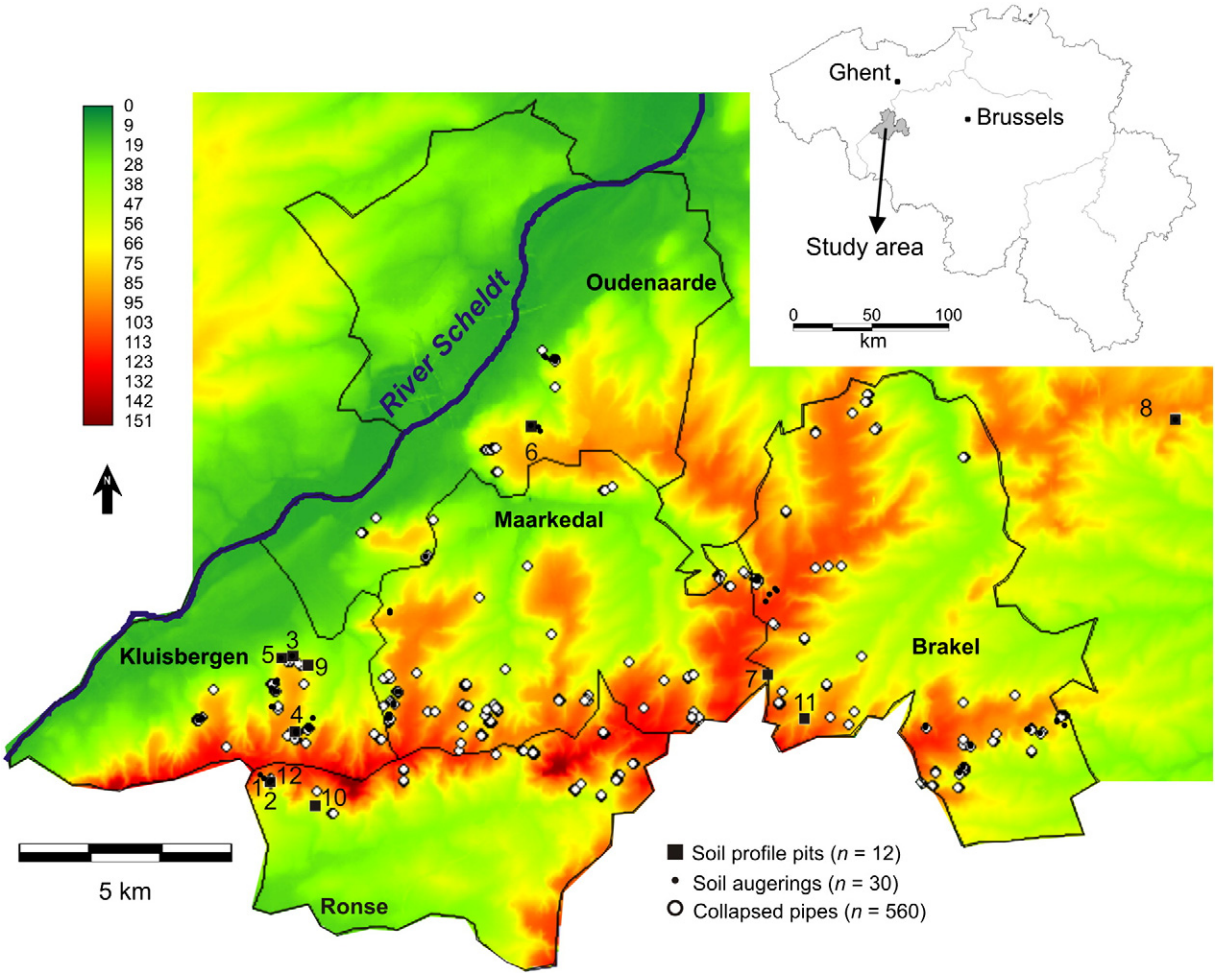

Fig. 1. Digital elevation model of the study area in the Flemish Ardennes (Belgium) with the location of collapsed pipes (CP) and the sites where soil profiles were investigated by means of profile pits: pastures with CP (1 = RO5-1, 2 = RO5-2, 3 = KL9, 4 = KL1), pastures without CP (5 = Z1, 6 = Z2, 7 = Z3, 8 = Z4), arable land (9 = A1, 10 = A2) and forest (11 = B1, 12 = B2); or by means of augering.