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PIPING AS A PROCESS OF GULLY EROSION IN SMALL-FORMAT AERIAL PHOTOGRAPHY. A SHORT NOTE

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Piping is one of the geomorphologic processes that are most difficult to quantify, because it can hardly be examined by conventional field survey methods and just as little by most remote sensing methods. Bridging the resolution gap between terrestrial and conventional aerial photography, small-format aerial photography taken by unmanned platforms from low flying heights (50-500 m) has proven to be an excellent tool for gully erosion monitoring in several research studies conducted by the authors (e.g. Marzolff and Ries, 2007; Aber *et al.*, 2010; Marzolff *et al.*, 2011). This kind of high-resolution photo-monitoring also enables the documentation of piping forms and provides clues to the process dynamics and to the function of piping as an initializing process for gully incision/erosion.

Other than from the ground perspective, the spatial orientation of piping holes becomes visible on the small-format aerial photographs, which allows analysing the linear structures and the relation of the locations of piping holes to subsurface-drainage lines. The presented examples provide evidence for the thesis that piping often has a preparative function for rill and gully erosion processes, both at the gully headcut as well as at the sidewalls and the tributaries. Piping may also affect the gully bottom (Ries and Marzolff, 2003).

Piping processes often occur next to man-made forms such as bench terraces, small earth dams around headcuts and in connection with land-levelling measures. Accordingly, the dynamics of piping processes are subject to high spatio-temporal variability, increasing both the challenge and difficulty of quantification.

In Fig. 1, the corner of a cereal field in the Bardenas Reales (Province of Navarra, Spain) is still patterned by repeated tractor crossings one year after the last tillage. Soil sealing and crusting has led to the development of a deeply incised narrow gully (image A; Giménez *et al.*, 2009). The field slopes slightly from top to bottom in the image, but the tributary rills and upper part of the gully follow the furrows of the last tillage

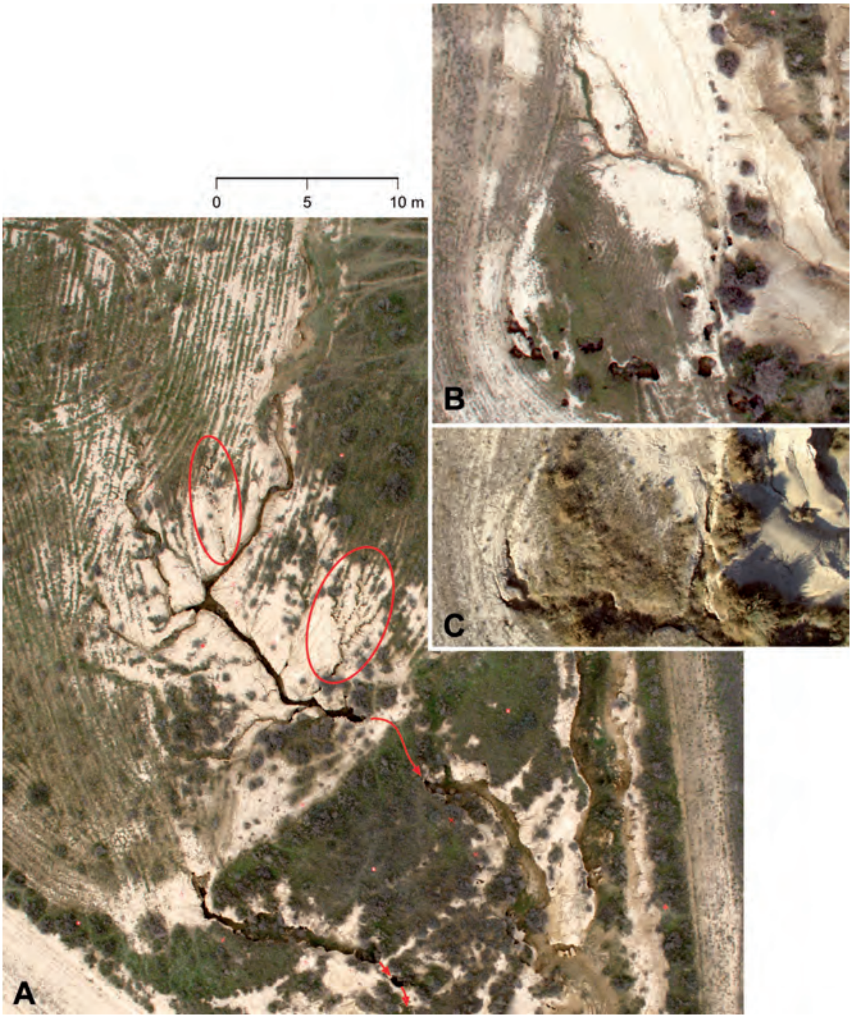

Figure 1. Gully Bardenas Reales 2 (Province of Navarra, Spain), February and October 2007.

operation rather than the general inclination. Chains of piping holes (red circles) indicate the subsurface rill course, partly guided by an underlying, older tillage pattern. At the lower edge of the field, the gully drains into a larger gully at the right image side through a 5 m long subsurface connection also created by piping processes (red arrow). Close by, a series of much larger piping holes draining into the same gully (image B; same scale) is already tracing the future course of another small gully: Eight months after this image was taken, the tunnel sections had caved in, revealing a continuous linear incision 15 m long and about 80 cm deep (image C).

CIG 37 (1), 2011, p. 115-120, ISSN 0211-6820

Figure 2. Barranco Rojo, (near Botorrita, Province of Zaragoza, Spain), October 2006.

The aerial photograph of the upslope end of Barranco Rojo (Fig. 2), which cuts into Quaternary alluvial fills deposited in the Huerva catchment, reveals the evolution of the gully from a series of interconnected piping holes that have grown together by collapsing "interfluves". Stereo-photo analysis of the internal watersheds has shown that the gully part covered by the image is partitioned into 32 separate, subterraneously draining parts. Between 2002 and 2009, the gully has grown exclusively by enlargement of the topmost piping holes adjacent to the dirt track (15.6 m^2, corresponding to at least 15.4 m^3; Marzolff *et al.*, 2011). The pipes act as runoff collectors for the surface water which runs along the terrace bench next to the cereal field in the lower right – one of the main drainage lines of the upslope catchment area (Marzolff and Ries, 2007; Seeger et al., 2009). The occurrence and amount of piping involved in this gully's development may well be related to the land-levelling activities undertaken for the creation of the surrounding agricultural terraces: Piping holes and breaches of terrace banks can be observed at many places in the immediate vicinity.

Gully Talaâ (Fig. 3) is situated in an abandoned field near Taroudant, where the large sediment fans of the High Atlas have been dissected into extensive badlands for the last two hundred years. Dense networks of large and deep rills that have reached upslope as far as the watershed leave only a small path on the divide to the next gully system. Only few of the rills appear as clearly linear features in the airphoto: nearly all are fragmented into short sections interconnected by pipes. 644 such piping holes

Figure 3. Gully Talaâ (Souss Basin, Morocco), March 2006.

(5800 pipes/ha) and subterraneous rill connections were mapped in the gully part covered by this image, locally reaching a density of up to 1.6 pipes/m². As one of the main Moroccan regions for vegetables, citrus fruit and banana plantations, the Souss Basin is an area under high land-use pressure, and many erosion-affected abandoned fields and badlands are now being levelled with bulldozers to enlarge the area for agro-industrial cultivation. The gully system, which is already visible on satellite images from 1968, might have been infilled and levelled some time before 2005. The reason for the extraordinary density of piping holes tracing subterraneous drainage lines might be the pre-existence of an older, buried drainage network that is now being uncovered by revived erosion processes.

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