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Challenges in gully erosion research

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Abstract: Although the number of publications on gully erosion has increased over the last decade, there are still various aspects of gully erosion that deserve more research efforts. Some of these, discussed in this contribution, are gully erosion in historical times, measuring techniques, processes of gully initiation, development and infilling, the interaction between gully erosion with hydrological and other soil degradation processes (e.g. piping, landsliding, tillage erosion and erosion induced by land levelling), gully erosion models, effective and efficient gully prevention and control measures. A better understanding of these aspects would allow one to better predict the impact of environmental change, gully prevention and control measures on gully erosion and gully infilling rates at a range of temporal and spatial scales and for various types of environments, and the effects of gully erosion on sediment yield, hydrological process intensities and landscape evolution.

Keywords: ancient gully, monitoring technique, gully model, gully prevention, gully control

Introduction

Taking steps to prevent or control gully erosion should require no justification. This soil degradation process negatively affects on site (both in the gully and the inter-gully area) several soil functions (e.g.: biomass, food and fibre production, water filtering function, bearing function, ecological function, archive function) and hence soil quality. In addition, gully erosion represents a major sediment-producing process, generating between 10 and 95% of total sediment mass at catchment scale whereas gully channels often occupy less then 5% of the total catchment area (Poesen et al. 2003). Furthermore, gully channel development increases runoff and sediment connectivity in the landscape, hence increasing the risk for flooding and reservoir sedimentation significantly.

Over the last decade, significant progress in the understanding of gully erosion and its controlling factors has been made and over 85 research papers were published in special issues of international journals and books following international conferences on gully erosion: i.e. Poesen et al. 2003 (proc. Leuven symposium in 2000), Li et al. 2005 (proc. Chengdu symposium in 2002), Valentin et al. 2005 (proc. Chengdu symposium in 2002), Römkens & Bennett 2005 (proc. Oxford, MS, USA symposium in 2004) and Casali et al. 2009 (proc. Pamplona symposium in 2007). In addition between 2000 and 2010 over 600 papers discussing various aspects of gully erosion were reported in the Web of Science.

Yet, there are still several unanswered questions related to gully erosion. I will address and illustrate some of these questions or knowledge gaps as they are rather important for a better understanding of gully erosion and therefore for improving prediction, prevention or control of gully erosion. These questions still present major challenges for the scientific community.

Why studying historical gully erosion?

Assessing the interactions between environmental change (land use, climate) and land degradation remains a key issue for environmental scientists, managers and policymakers. Why? Two quotes by Lang & Bork (2006) provide the answer: “Those who cannot remember the past are condemned to repeat it” and “The past is the key to the present and the future”. Gullies are one of the few morphological evidences of past soil erosion periods reflecting impacts of environmental changes (land use, extreme rain events) in the landscape. In fact, gullies are ideal geomorphic features to unravel human-environment interactions induced by particular socio-economic

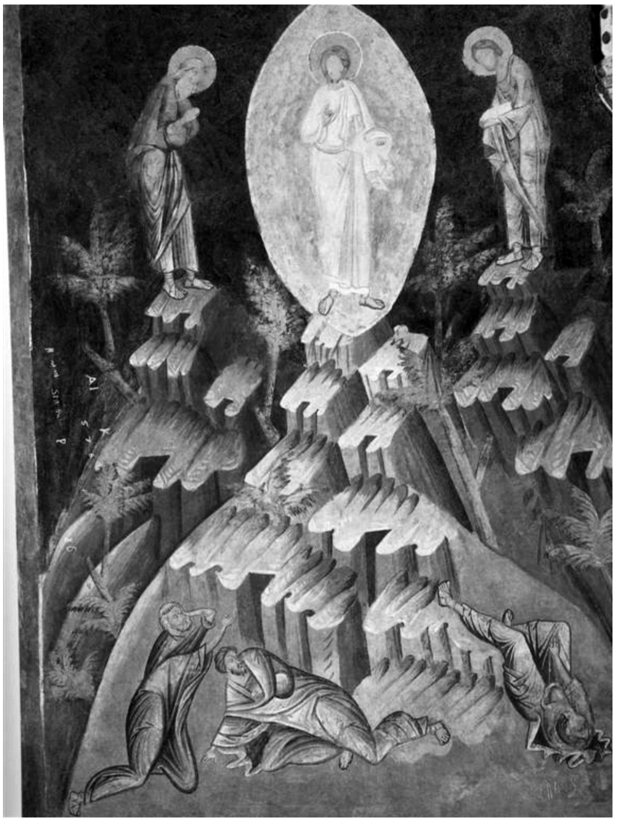

Fig. 1. Excerpt of the fresco "The transfiguration", northern wall of the choir in the Holy Trinity Chapel of Lublin Castle, Lublin, Poland, painted by Andrei in 1416. This fresco depicts landforms which resemble gully channels. It is likely that the painter was inspired by gullies he observed in the Lublin region in the early 15th century

conditions in historical times. Therefore, detailed studies of historical gullies are crucial, not only to reconstruct the past but also to learn from it. Historical paintings clearly suggest that gullies also occurred in the past (Fig. 1).

Moreover, there is ample physical evidence of major historical gully erosion phases in various parts of the world. Some of these have been studied in detail and have revealed strong increases in gully erosion as a consequence of particular land use changes (sometimes in combination with extreme rain events) induced by socio-economic changes, such as the conversion of forest to cropland (starting already in prehistoric and Roman periods, e.g. in Belgium, Germany, Poland), overgrazing in mountain areas as a consequence of transhumance (e.g. France, Spain), expansion of vineyards (e.g. Spain), conversion of Mediterranean shrub land to cropland (e.g. for wheat and almond production) or to improved pastures, expansion of maize cultivation in cropland in the European loess belt, or the application of soil and water conservation measures on hill slopes resulting in an increased gully channel incision due to reduced sediment input from the hill slopes (e.g. in Ethiopia). Other studies have also documented the complete stabilization of gully systems as a consequence of reforestation (e.g. in Belgium, France, Poland, China, USA). However, there are still many of these "old" gully systems which have not yet been analyzed in detail, nor have they been dated. There is a particular need to combine detailed field observations and process-based knowledge of contemporary gullying and dating techniques to reconstruct conditions leading to gully channel incision, development and infilling. Most studies on gully erosion deal with gully channel development, very few with conditions leading to channel infilling. Yet this process is equally important to better understand gully dynamics.

What are appropriate measuring techniques for monitoring or better understanding of the initiation, development and infilling of various gully types at various temporal and spatial scales?

Classical aerial photos rarely provide sufficient detail for gully monitoring, hence low-altitude aerial photos are needed and this approach has been recently explored by various researchers in Germany, Spain and the USA. For instance Marzolff & Poesen (2009) explored the potential of 3D gully monitoring with GIS using high-resolution (low-altitude) photography and a digital photogrammetric system to document gully head evolution over a 6 year period. Short-term gully head retreat monitoring only reveals short-term retreat rates and these can be significantly different from long-term retreat rates. Hence there is a need for longer term monitoring, not only of gully heads but also of entire gully channels to better understand gully dynamics.

Studying gully channels under forest canopy has now been made more feasible using LiDAR data (e.g. James at al. 2007). Significant advances in the detection of in-filled gullies on top of tertiary landscapes in Belgium were recently made by Saey et al. (2008) using electromagnetic induction sensors. There is a need to further develop and to apply these new techniques to a wider range of gully environments so as to define their possibilities and limitations.

What processes lead to gully development and infilling?

Processes leading to ephemeral gully development in cropland are relatively well understood. However, gully development in other types of environment is less well understood.

Piping. For instance, in pasture land of northern Europe or abandoned cropland on Neogene marls in the Mediterranean, discontinuous gullies have been reported to occur regularly. These gullies as well as bank gullies are often preceded by intense soil piping. The areal extent of the land seriously at risk from piping erosion in Western Europe has been estimated to exceed 260 000 km^2 (Faulkner 2006). The limited amount of data also shows that soil losses by piping may often exceed soil loss tolerance values. So far, factors controlling soil piping and incipient gullying are poorly understood and these processes deserve more attention through controlled laboratory experiments as well through detailed field monitoring studies.

Urban gullies and road gullies. Urban sprawl often leads to a dramatic increase of peak runoff, runoff coefficients and a concomitant reduction of runoff concentration times. In many parts of the world (particularly in the Third World) this leads to the rapid development of large gully channels (urban gullies) endangering the bearing function of soils and causing damage to infrastructure and private property. Likewise, improper drainage of rural roads in tropical environments often results in the rapid development of large gully channels turning the often unpaved roads into road gullies (Fig. 2).

Gully infilling. Over 95% of gully erosion research deals with factors controlling incipient gullying and gully expansion. Very few studies have focussed on environmental conditions leading to gully infilling. Yet, we know from particular case studies (e.g. in Belgium, Romania) that several cycles of gully cutting and infilling have taken place in a time span of decades to centuries. If we want to better predict gully evolution and to develop proper gully management strategies we need to better understand factors controlling gully infilling.

Fig. 2. Artists' view of a road gully in DR Congo (Asimba Bathy 2009)

How does gully erosion interact with hydrological and other soil degradation processes?

Once gully channels develop they interact with hydrological processes: e.g. drainage of the inter-gully area may lead to desiccation phenomena and crop yield losses in semi-arid environments (as observed in North Ethiopia) or runoff transmission losses through the gully bed and banks may affect groundwater recharge and possible groundwater contamination (as observed in Belgium, Israel and Niger). Few studies have focussed on these interactions which are crucial for a better management of water resources.

In the previous section we reported the importance of the interactions between piping erosion and gully erosion. Piping erosion may trigger gully erosion but also gully erosion may induce piping erosion. Along the same lines, shallow landslides may affect piping and gully development (by redirecting subsurface and surface runoff) and in turn gully channel development may affect shallow landslide activity by either draining the landslide or by removing material displaced by the landslide (Fig. 3).

Fig. 3. Illustration of the interactions between ephemeral gullying and shallow landsliding in cropland (wheat) on flysch-derived soils near Villanueva De La Concepcion, South Spain (April 2010)

This area received almost a double rain depth in the winter season (compared to the normal rain depth) leading to widespread ephemeral gully development and shallow landsliding in cropland. Note that the position of the two main ephemeral gully channels (i.e. at the border of the landslide toe) is controlled by the change in topography induced by the shallow landslide. It is likely that the ephemeral gully channel incision enhances drainage of the landslide zone, hence leading to an increase of the factor of safety.

In cropland, ephemeral gullies are usually filled in by tillage (tillage erosion and tillage deposition) within less than a year starting from their initiation. During subsequent storms (years), the in-filled soil material is usually eroded again by concentrated flow thereby increasing the plan-form concavity of the site.

The newly created plan-form concavity increases the probability for concentrated flow erosion. So ephemeral gully erosion and tillage erosion reinforce each other (Poesen et al. 2003, 2010). Routine infilling of ephemeral gully channels during tillage practices may result in markedly higher rates of soil loss as compared to allowing these gullies to persist in the landscape, demonstrating a further advantage of adopting no-till management practices.

In various parts of Europe, heavily dissected landscapes by gullying (badlands) have been levelled, thereby causing strong soil profile truncation in the inter-gully areas and infilling of gullies with this material. Such land levelling operations have often resulted in renewed gully incision of the levelled land as well as in shallow landsliding causing large soil losses. In other words, important interactions exist between concentrated flow erosion and tillage erosion as well as with erosion caused by land levelling.

The significant interactions between gully erosion on the one hand and hydrological (i.e. infiltration, drainage) as well as other soil erosion processes (piping, mass wasting, tillage erosion and erosion by land levelling) on the other need to be better understood for improving predictions of hydrological response and land degradation rates for various environmental change conditions. This improved understanding is the basis for taking appropriate and effective measures to control soil erosion.

Do we have good gully erosion models?

Poesen et al. (2011) recently reviewed the gully erosion literature dealing with prediction of gully erosion. Although several attempts have been made to develop empirical and process-based models for predicting either gully sub processes or gully erosion rates in a range of environments, there are still no reliable (i.e. validated) models available allowing one to predict effects of environmental change on gully erosion or gully infilling rates at various temporal and spatial scales, and the impacts of gully erosion on sediment yield, hydrological processes and landscape evolution. This is a major research area requiring more efforts.

What are effective and efficient gully prevention and gully control measures?

Poesen & Valentin (2003) observed that innovation in gully erosion control research is very limited compared to innovation in gully erosion process research. In many areas affected by gully erosion classical erosion control techniques are being applied, i.e. grassed waterways to control ephemeral gully erosion, reforesting (replanting) gully channels and gully banks or installing check dams. In most cases these measures seem to work. However, a number of case studies reveal that some of these measures are not as effective as expected (e.g. check dams in Spanish gullies). Therefore, more studies are needed to determine the effectiveness and efficiency of gully erosion control programmes at various temporal and spatial scales. In other words, what can we learn from successes and failures?

Revegetation. Various species have the potential to control gully erosion. A methodological framework was recently proposed to evaluate both above- and below-ground biomass characteristics of various Mediterranean shrub and tree species as to their effectiveness in controlling gully erosion (De Baets et al. 2009). Such methodology needs to be applied to different environments so as to select the most suitable species. When revegetation of gully channels is practised more information is also needed on topographic limits (in terms of slope gradient, aspect) beyond which revegetation will fail (Bochet et al. 2009). Controlling piping-induced gully erosion remains perhaps the biggest challenge in erosion control research.

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References

Asimba B., 2009. *Respect for the environment*. Dimensie 3 on DR Congo. May–July 2009 (3): 10.

Bochet E., Garcia-Fayos P. & Poesen J., 2009. Topographic thresholds for plant colonization on semi-arid eroded slopes. *Earth Surface Processes and Landforms* 34: 1758–1771 (DOI:10.1002/esp.1860).

Casali J., Giménez R. & Bennett S., 2009. Gully erosion processes and modelling. Proc. Fourth International Symposium on Gully Erosion, Pamplona, Spain, September 2007, *Earth Surface Processes and Landforms* 34: 1839–1984.

De Baets S., Poesen J., Reubens B., Muys B., De Baerdemaeker J. & Meersmans J., 2009. Methodological framework to select plant species for controlling rill and gully erosion: application to a Mediterranean ecosystem. *Earth Surface Processes and Landforms* 34: 1374–1392 (DOI: 10.1002/esp.1826).

Faulkner H., 2006. Piping hazard on collapsible and dispersive soils in Europe. In: Boardman J. & Poesen J. (eds.) *Soil Erosion in Europe*. Wiley, Chichester, UK: 537–562.

James LA, Watson D.G. & Hansen W.F., 2007. Using LiDAR data to map gullies and headwater streams under forest canopy: South Carolina, USA. *Catena* 71 (1): 132–144.

Lang A. & Bork H.R., 2006. Past soil erosion in Europe. In: Boardman, J. & Poesen, J. (Eds.) *Soil Erosion in Europe*. Wiley, Chichester, UK: 465–476.

Li Y., Poesen J. & Valentin C., 2004. *Gully Erosion under Global Change*. Proc. Second International Symposium on Gully Erosion, Chengdu, China, May 2002. Sichuan Science and Technology Press, Chengdu, China: 354 pp.

Marzolff I. & Poesen J., 2009. The potential of 3D gully monitoring with GIS using high-resolution aerial photography and a digital photogrammetry system. *Geomorphology* 111: 48–60 (doi:10.1016/j.geomorph.2008.05.047).

Poesen J., Nachtergaele J., Verstraeten G. and Valentin C., 2003. Gully erosion and environmental change: importance and research needs. *Catena* 50 (2–4): 91–133.

Poesen J. & Valentin C., 2003. Gully Erosion and Global Change. Proc. First International Symposium on Gully Erosion, Leuven, Belgium, April 2000. *Catena* 50 (2–4): 87–562.

Poesen J., Torri D. & Vanwalleghem T., 2011. Gully Erosion: Procedures to Adopt When modelling Soil Erosion in Landscapes Affected by Gullying. In: Morgan R.P.C. & Nearing M.A. (eds.) *Handbook of Erosion Modelling*. Blackwell Publishing Ltd, Chichester, UK. Chapter 19: 360–386 + Plates 16–19.

Römkens M.J.M. & Bennett S.J., 2005. Gully Erosion. Proc. Third International Symposium on Gully Erosion, Oxford, MS, USA, April 2004. *International Journal of Sediment Research* 20 (3): 157–280.

Saey T., Simpson D., Vitharana UWA, Vermeersch H., Vermang J. & Van Meirvenne M., 2008. Reconstructing the paleotopography beneath the loess cover with the aid of an electromagnetic induction sensor. *Catena* 74: 58–64 (doi:10.1016/j.catena.2008.03.007).

Valentin C., Poesen J. & Li Y., 2005. Gully Erosion: A Global Issue. Proc. Second International Symposium on Gully Erosion, Chengdu, China, May 2002. *Catena* 63 (2–3): 129–330.