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Invited review

How fast do gully headcuts retreat?

Matthias Vanmaercke [a,b,*], Jean Poesen [a], Bert Van Mele [a], Matthias Demuzere [a,b], Amber Bruynseels [a], Valentin Golosov [c,d], José Fernando Rodrigues Bezerra [e], Sergey Bolysov [c], Aleksandr Dvinskih [d], Amaury Frankl [f], Yulia Fuseina [c], Antônio José Teixeira Guerra [g], Nigussie Haregeweyn [h], Ion Ionita [i], Fils Makanzu Imwangana [j,k], Jan Moeyersons [l], Itshack Moshe [m], Aliakbar Nazari Samani [n], Lilian Niacsu [i], Jan Nyssen [f], Yoshinori Otsuki [o], Maria Radoane [p], Ivan Rysin [q], Yuri V. Ryzhov [r], Oleg Yermolaev [d]

[a] Division of Geography and Tourism, Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium
[b] Research Foundation Flanders (FWO), Brussels, Belgium
[c] Faculty of Geography, Moscow State Lomonosov University, Moscow, Russia
[d] Institute of Ecology and Environmental Sciences, Kazan Federal University, Kazan, Russia
[e] Geography and History Department, State University of Maranhão, São Luís City, Brazil
[f] Department of Geography, Ghent University, Ghent, Belgium
[g] Department of Geography, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil
[h] International Platform for Dryland Research and Education, Tottori, Japan
[i] Department of Geography, "Alexandru Ioan Cuza" University of Iasi, Iasi, Romania
[j] Laboratoire de Géomorphologie et Télédétection, Centre de Recherches Géologiques et Minières, Kinshasa, Congo
[k] Department of Geosciences, Faculty of Sciences, University of Kinshasa, Kinshasa, Congo
[l] Royal Museum for Central Africa, Tervuren, Belgium
[m] Forestry and Soil Conservation Division, Keren Kayemeth LeIsrael, Southern Region, Gilat, Israel
[n] Faculty of Natural Resources, University of Tehran, Tehran, Iran
[o] Institute of Geography, Tohoku University, Sendai, Japan
[p] Department of Geography, 'Stefan cel Mare' University, Suceava, Romania
[q] Department of Ecology and Environmental Sciences, Udmurt State University, Izhevsk, Russia
[r] Institute of Geography, Siberian Branch, Russian Academy of Sciences, Irkutsk, Russia

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ABSTRACT

Gully erosion has important on and off site effects. Therefore, several studies have been conducted over the past decades to quantify gully headcut retreat (GHR) in different environments. Although these led to important site-specific and regional insights, the overall importance of this erosion process or the factors that control it at a global scale remain poorly understood. This study aims to bridge this gap by reviewing research on GHR and conducting a meta-analysis of measured GHR rates worldwide. Through an extensive literature review, GHR rates for 933 individual and actively retreating gullies have been compiled from more than 70 study areas worldwide (comprising a total measuring period of >19 600 years). Each GHR rate was measured through repeated field surveys and/or analyses of aerial photographs over a period of at least one year (maximum: 97 years, median: 17 years). The data show a very large variability, both in terms of gully dimensions (cross-sectional areas ranging between 0.11 and 816 m^2 with a median of 4 m^2) and volumetric GHR rates (ranging between 0.002 and 47 430 m^3 $year^{-1}$ with a median of 2.2 m^3 $year^{-1}$). Linear GHR rates vary between 0.01 and 135 m $year^{-1}$ (median: 0.89 m $year^{-1}$), while areal GHR rates vary between 0.01 and 3628 m^2 $year^{-1}$ (median: 3.12 m^2 $year^{-1}$). An empirical relationship allows estimating volumetric retreat rates from areal retreat rates with acceptable uncertainties. By means of statistical analyses for a subset of 724 gullies with a known contributing area, we explored the factors most relevant in explaining the observed 7 orders of magnitudes of variation in volumetric GHR rates. Results show that measured GHR rates are significantly correlated to the runoff contributing area of the gully ($r^2 = 0.15$) and the rainy day normal (RDN; i.e. the long-term average annual rainfall depth divided by the average number of rainy days; $r^2 = 0.47$). Other factors (e.g. land use or soil type) showed no significant correlation with the observed GHR rates. This may be attributed to the uncertainties associated with accurately quantifying these factors. In addition, available time series data demonstrate that GHR rates are subject to very large year-to-year variations. As a result, average GHR rates measured over short (<5 year) measuring periods may be subject to very large (>100%) uncertainties. We integrated our findings into a weighted regression model that simulates the volumetric retreat rate of a gully headcut as a function of upstream drainage area and RDN. When

* Corresponding author at: KU Leuven, Division of Geography and Tourism, Celestijnenlaan 200E, 3001 Heverlee, Belgium.
E-mail address: matthias.vanmaercke@ees.kuleuven.be (M. Vanmaercke).

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