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Invited review

### How fast do gully headcuts retreat?



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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<sup>2</sup> with a median of 4 m<sup>2</sup>) and volumetric GHR rates (ranging between 0.002 and 47 430 m<sup>3</sup> year<sup>-1</sup> with a median of 2.2 m<sup>3</sup> year<sup>-1</sup>). Linear GHR rates vary between 0.01 and 135 m year<sup>-1</sup> (median: 0.89 m year<sup>-1</sup>), while areal GHR rates vary between 0.01 and 3628 m<sup>2</sup> year<sup>-1</sup> (median: 3.12 m<sup>2</sup> year<sup>-1</sup>). 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

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