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Data-driven prediction of gully densities and erosion risk at the global scale

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Gully erosion is a key driver of soil erosion and land degradation in many regions worldwide, leading to important on- and offsite impacts. While numerous studies have focussed on understanding gully erosion at local scales, we have very little insights into the patterns and controlling factors of this process at a global scale. Overall, gully erosion remains notoriously difficult to simulate and predict. A main reason for this is that the complex and threshold-dependent nature of gully formation leads to very high data requirements when aiming to simulate this process over larger areas.

Here we help bridging this gap by presenting the first data-driven analyses of gully head densities at a global scale. For this, we developed a grid-based scoring method that allows to quickly assess the range of gully head densities in a given area based on Google Earth imagery. Using this approach, we constructed a global database of mapped gully head densities for around 20,000 sites worldwide. Based on this dataset and globally available data layers on relevant environmental factors (topography, soil characteristics, land use) we explored which factors are dominant in explaining global patterns of gully head densities and propose a first global gully head density map as well as a gully erosion risk map. The latter combines gully density with estimates of the likely expansion rates of gullies. For this we use a combination of machine learning techniques and empirical modelling.

Our results indicate that there might be are around 2 billion gully heads worldwide. This estimate might underestimate the actual numbers of gully heads since ephemeral gullies (in cropland) and gullies under forest remain difficult to map. Our database and analyses further reveal clear regional patterns in the presence of gullies. Around 27% of the terrestrial surface (excluding

Antarctica and Greenland) has a density of > 1 gully head/km^2, while an estimated 14% has a density of > 10 gully heads/km^2 and 4% has even a density of > 100 gully heads/km^2. Major hotspots (with > 50 gully heads/km^2) include the Chinese loess plateau, but also Iran, large parts of the Sahara Desert, the Andes and Madagascar. In addition, gully erosion also frequently occurs (with typical densities of 1-50 gully heads/km^2) in the Mid-West USA, the African Rift, SE-Brazil, India, New-Zealand and Australia.

These regional patterns are mainly explained by topography and climate in interaction with vegetation cover. Overall, the highest gully densities occur in regions with some topography and a (semi-)arid climate. Nonetheless, it is important to point out that not all gully heads are still actively retreating. Building on earlier insights into the magnitude and controlling factors of gully head retreat rates, we hypothesize that hotspots in terms of gully erosion are mostly situated in somewhat more humid and densely cultivated areas. Based on this, we explore what our current results imply for assessing actual gully erosion rates at a global scale.