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How to quantify and predict gully erosion and its contribution to catchment sediment yield at regional scales? A test-case for the Horn of Africa

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Gully erosion is a major cause of land degradation in many regions, due to its negative impacts on catchment hydrology, its associated losses of land and damage to infrastructure, as well as due to its often major contributions to catchment sediment yields. Mitigation and prevention of gully erosion requires a good knowledge of its spatial patterns and controlling factors. However, our ability to simulate or predict this process remains currently very limited. This is especially the case for the regional scale. Whereas detailed case studies have provided important insights into the drivers of gully erosion at local scales, these findings are often difficult to upscale to larger regions.

Here we explore to what extent gully erosion and its contribution to catchment sediment yield (SY) can be simulated at the regional scale. For this we compiled different datasets on observed gully densities in the Horn of Africa (Ethiopia, Eritrea and Djibouti) using Google Earth imagery. A first dataset includes estimates of the aerial fraction of gullies for > 100 catchments and sites. The second dataset consists of individually mapped gully heads for > 300 test sites of 1 km^2. Correlation analyses showed that patterns of gully density are mainly controlled by vegetation (NDVI), topography (average slope steepness) and rainfall patterns (number of rainy days). Combined in a multiple-regression model, these factors explained about 40% of the observed variation in aerial gully densities. A similar approach worked less well when aiming to predict observed patterns of gully head density. Error analyses showed that uncertainties on the mapped gully densities are an important source of error. However, most of the unexplained variance is attributable to model errors.

Furthermore, a confrontation between mapped gully densities and observed SY data showed that aerial gully densities correlated significantly with SY (r^2 = 0.44). However, correlations between SY and the mapped number of gully heads were clearly stronger (r^2 = 0.62). This confirms that gullies play a key role in explaining patterns of SY across the horn of Africa. However, it also suggests that their role as direct source of sediments (e.g. through gully head retreat) is likely more important than their indirect impact on sediment connectivity.

Overall, our results indicate that gully head densities are likely a more useful proxy to quantify gully erosion and its contribution to SY than gully densities expressed as aerial fractions. Nonetheless, spatial patterns of gully head densities are harder to predict with an empirical regression approach. More accurate predictions of gully erosion and its contribution to SY therefore requires a spatially explicit and more process-oriented modelling approach.