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Comparative analysis of the Copernicus (30 m), TanDEM-X (12 m) and UAV-SfM (0.2 m) DEM to estimate gully volumes and mobilization rates in central Madagascar

Liesa Brosens[1], Benjamin Campforts[2], Gerard Govers[1], Emilien Aldana-Jague[3], Vao Fenotiana Razanamahandry[1], Tantely Razafimbelo[4], Tovonarivo Rafolisy[4], and Liesbet Jacobs[5]

[1]Department of Earth and Environmental Sciences, KU Leuven, Leuven, Belgium (liesa.brosens@kuleuven.be)
[2]Institute for Arctic and Alpine Research, University of Colorado at Boulder, Boulder, CO
[3]Earth and Life Institute, Université Catholique de Louvain, Louvain-la-Neuve, Belgium
[4]Laboratoire des Radio Isotopes, Université d'Antananarivo, Antananarivo, Madagascar
[5]Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, Amsterdam, Netherlands

Over the past decades advanced technology has become available, revolutionizing the assessment of surface topography. At smaller scales (up to a few km²) structure from motion (SfM) algorithms applied to uncrewed aerial vehicle (UAV) imagery now allow sub-meter resolution. On the other hand, spaceborne digital elevation models (DEMs) are becoming increasingly accurate and are available at a global scale. Two recent spaceborne developments are the 12 m TanDEM-X and 30 m Copernicus DEMs. While sub-meter resolution UAV-SfM DEMs generally serve as a reference, their acquisition remains time-consuming and spatially constrained. However, some applications in geomorphology, such as the estimation of regional or national erosion quantities of specific landforms, require data over large areas. TanDEM-X and Copernicus data can be applied at such scales, but this raises the question of how much accuracy is lost because of the lower spatial resolution.

Here, we evaluate the performance of the 12 m TanDEM-X DEM and the 30 m Copernicus DEM to i) estimate gully volumes, ii) establish an area-volume relationship, and iii) determine sediment mobilization rates, through comparison with a higher resolution (0.2 m) UAV-SfM DEM. We did this for six study areas in central Madagascar where lavaka (large gullies) are omnipresent and surface area changes over the period 1949-2010s are available. Copernicus derived lavaka volume estimates were systematically too low, indicating that the Copernicus DEM is not suitable to estimate erosion volumes for geomorphic features at the lavaka scale (100 – 10^5 m²). The relatively coarser resolution of the DEM prevents to accurately capture complex topography and smaller geomorphic features. Lavaka volumes obtained from the TanDEM-X DEM were similar to UAV-SfM volumes for the largest features, while smaller features were generally underestimated. To deal with this bias we introduce a breakpoint analysis to eliminate volume reconstructions that suffered from processing errors as evidenced by significant fractions of negative volumes. This elimination allowed the establishment of an area-volume relationship for the TanDEM-X data with fitted coefficients within the 95% confidence interval of the UAV-SfM relationship. Combined with

surface area changes over the period 1949-2010s, our calibrated area-volume relationship enabled us to obtain lavaka mobilization rates ranging between 18 ± 3 and 311 ± 82 t ha^{-1} yr^{-1} for the six study areas, with an average of 108 ± 26 t ha^{-1} yr^{-1}. This does not only show that the Malagasy highlands are currently rapidly eroding by lavaka, but also that lavaka erosion is spatially variable, requiring the assessment of a large area in order to obtain a meaningful estimate of the average erosion rate.

With this study we demonstrate that medium-resolution global DEMs can be used to accurately estimate the volumes of gullies exceeding 800 m^2 in size, where the proposed breakpoint-method can be applied without requiring the availability of a higher resolution DEM. This might aid geomorphologists to quantify sediment mobilisation rates by highly variable processes such as gully erosion or landsliding at the regional scale, as illustrated by our first assessment of regional lavaka mobilization rates in the central highlands of Madagascar.