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Is there an environmental crisis in Madagascar's highlands? Insights from the spatio-temporal evolution and demographic modelling of lavaka (large gullies)

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The Malagasy highlands are scattered with large inverse teardrop-shaped gullies called lavaka, which are by many considered as the prime indication of a currently ongoing human-induced environmental crisis. Yet, these gullies are known to have existed long before human arrival on the island, resulting in the highly debated role of anthropogenic disturbances on their formation. Here, we assess the dynamics of 700 lavaka in the lake Alaotra region from 1949 to the 2010s by using historical aerial pictures and present day satellite imagery. An overall birth to stabilization ratio of 6.1 indicates a currently rapid growing lavaka population. Observed growth-, birth- and stabilization rates allowed us to calculate a mean lavaka population age of 410 ± 40 years, and estimate that the current crisis started at 943 ± 430 cal. yr BP. This timeframe corresponds well with the "subsistence-shift", where people move from hunting and foraging to farming and herding practices upon the introduction of cattle in the region. These findings were integrated into a novel, temporally explicit lavaka population model - building upon the observed lavaka growth-, birth- and stabilization rates and lavaka size distributions - where different environmental pressure scenarios were tested. Modelling outcomes show that the currently observed lavaka crisis largely results from a rapid increase in environmental pressure over the last centuries, likely caused by the combined effects of deforestation and overgrazing related to human population growth and the introduction of cattle. With this study we show the potential of an integrated data-modeling approach, where demographic concepts are applied to geomorphological features, allowing to link their evolution with past anthropogenically driven environmental changes.