A geoscience perspective on the gully erosion problem across the interior of southern Africa

AUTHOR:
Stephen Tooth[1]

AFFILIATION:
[1]Earth Surface Processes Research Group, Department of Geography and Earth Sciences, Aberystwyth University, Aberystwyth, Wales, United Kingdom

CORRESPONDENCE TO:
Stephen Tooth

EMAIL:
set@aber.ac.uk

HOW TO CITE:
Tooth S. A geoscience perspective on the gully erosion problem across the interior of southern Africa. S Afr J Sci. 2025;121(9/10), Art. #21672. https://doi.org/10.17159/sajs.2025/21672

ARTICLE INCLUDES:
☐ Peer review
☐ Supplementary material

KEYWORDS:
donga, erosion, geoscience, land use, soil

PUBLISHED:
29 September 2025

Significance:

Across southern Africa, gullies are highly visible forms of soil erosion. Gullies provide exposure of hillslope and river sediments, some of which contain fossils and archaeological artefacts. The causes of gully erosion have long been debated, with some researchers favouring human land-use changes, and others favouring natural factors (e.g. soil types, climate variations, base-level changes). This Invited Commentary outlines how geochronology can help determine the timing of gully formation and thus support inferences regarding causes of erosion. A geoscience perspective on the gully erosion problem advances our understanding of human–landscape interactions, with practical benefits for improved erosion control.

Introduction

Across large parts of the southern African interior, soil erosion by water and/or wind is a widespread phenomenon. Soil erosion by water includes sheet, rill and gully erosion, the latter commonly leading to highly dissected land surfaces, both in colluvial (e.g. hillslope, pediment) and alluvial (e.g. river terrace, floodplain) landforms.[1] In countries such as South Africa, Lesotho and Eswatini, individual gullies and coalesced gully networks ('badlands') are widely referred to as 'dongas', but in this Invited Commentary 'gully' is used as the catch-all term. Gullies range widely in size but can be up to several kilometres long, hundreds of metres wide, and tens of metres deep, and commonly provide extensive exposures of Quaternary sedimentary successions (Figure 1). Many of these successions provide evidence for past phases of sedimentation and palaeosol development interspersed with short phases of erosion (including by gullies), and may contain fossil faunal assemblages and/or archaeological artefacts (Figure 1F).[2,3] Consequently, gullies provide abundant opportunities for a range of geoscientific, palaeontological and archaeological investigations.

While gullies provide many scientific opportunities, their presence creates an impression of rapid, undesirable landscape change that has been attributed by some researchers to human causes, such as poor land management by Indigenous peoples or European settlers.[4,5] To try and control the deleterious on-site (e.g. loss of land) and off-site (e.g. reservoir sedimentation) impacts resulting from gully erosion, many resources have been devoted to so-called 'degraded/degrading' lands, including through gully stabilisation/rehabilitation efforts. Other researchers, however, have argued for natural causes of gully erosion, including decadal-scale climatic fluctuations, susceptible soil characteristics, and/or breaching of hard rock barriers along river beds.[6-8] Intrinsic land surface adjustments may also account for some gullies (e.g. valley floor oversteepening that leads to erosion and slope adjustment).[9,10] If correct, these alternative arguments imply that the affected land more correctly should be labelled as 'denuded/denuding'. In other words, is gully erosion across southern Africa dominantly a human-induced problem or is it mainly evidence of natural, ongoing landscape development? The answer has implications, not only for advancing our understanding of Earth surface dynamics and human–landscape interactions, but also for the targeting of the limited resources aimed at erosion control and sustainable land management.

Assessing the relative importance of human and natural causes of gully erosion is contingent on better constraining the age of gullies. In any given topographic setting, when did gullies first start to form, and how quickly have they developed? Does the timing of gully initiation, and any subsequent phases of accelerating/decelerating development, coincide with known human migration or settlement patterns and/or major land use changes, or are there firmer correlations with known palaeoenvironmental (e.g. climatic, vegetation) changes? Erosional landforms are challenging to age using geochronological techniques such as radiocarbon or luminescence dating because the formative processes tend to involve the removal – rather than the preservation – of dateable evidence (e.g. organic or clastic deposits). Nevertheless, building on a body of research developed within and beyond southern Africa over past decades, Lyons et al.[11] have shown how field, geochronological and archival data sets can be combined to help constrain the timing of initiation and subsequent development of gullies, and thus improve assessments of the relative importance of human and natural causes.

The purpose of this Invited Commentary is to: (1) summarise the main findings of Lyons et al.[11]; (2) compare these findings to previous studies of gullies and assess the potential for wider deployment of the investigative approach to other sites across the southern African interior; and (3) outline some of the nuanced aspects of the commonly polarised 'human versus natural causes' debate that might form the basis for future investigations and help improve erosion control.

Disentangling human and natural causes of erosion

To assess the relative importance of human and natural causes, Lyons et al.[11] investigated the age of gullies at three widely spaced sites across the interior of South Africa: (1) hillslopes in the upper Blood River catchment, KwaZulu-Natal; (2) river terraces at Erfkroon, located along the middle Modder River, western Free State; and (3) colluvial/alluvial fills along an unnamed tributary of the Moopetsi River ('the Moopetsi tributary'), Steelpoort region, Limpopo Province. At the Blood River site, gullies have formed in hillslope colluvium and are discontinuous, as they are not connected to an incised river channel downslope. At the Modder River and Moopetsi tributary sites, gullies have formed in colluvium and/or alluvium and are continuous, as they are connected to deeply incised river channels.

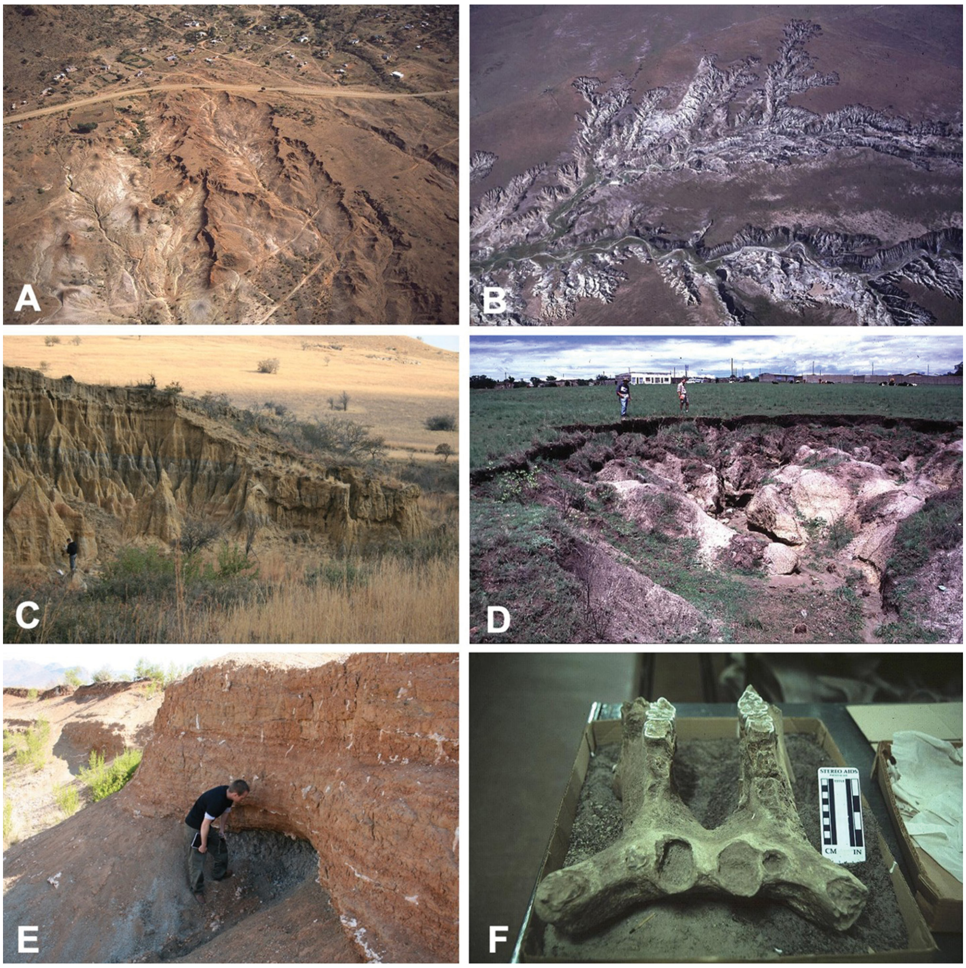
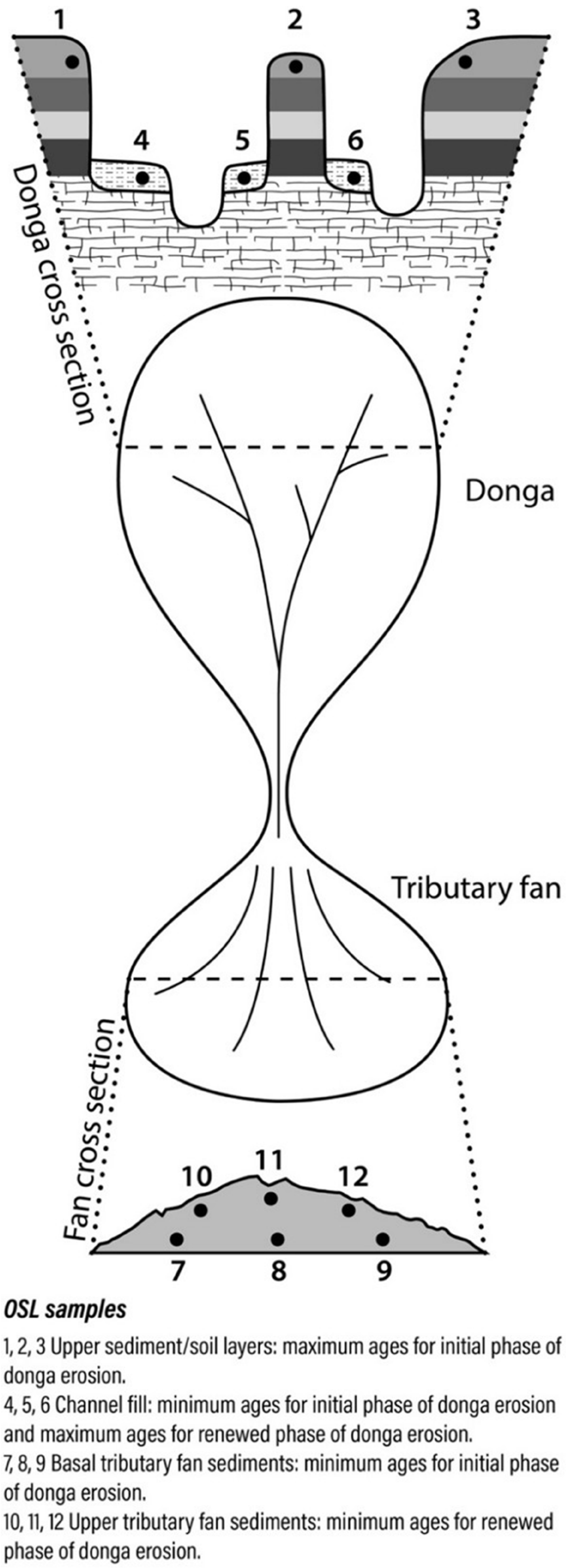


Figure 1: Examples of gullies and associated features from across parts of the South African interior. (A), (B) Aerial views of hillslope gullies in the Steelpoort region, Limpopo, and the Standerton region, Mpumalanga, respectively. (C) Gully sidewall showing interbedding of hillslope parallel, relatively unweathered sediments (lighter layers) and palaoesols (darker layers) in the upper Blood River valley, KwaZulu-Natal. (D) Gully headwall showing piping and slumping of colluvial and alluvial sediments in the Cornelia region, Free State. (E) Gully sidewall showing an example of a palaeosol (lowermost dark grey unit) that has been erosively truncated and overlain by hillslope parallel gravelly sand (orangey-brown unit) in the Steelpoort region, Limpopo. Rhizoliths and reworked nodules of calcium carbonate (white material) are evident in the gravelly sands. (F) Lower jaw of an archaic hippopotamus, recovered from sediments exposed in gullies at Erfkroon, Free State.

At all three sites, geomorphological and sedimentological field investigations, together with optically stimulated luminescence (OSL) dating of exposed sediments, were undertaken to constrain the timing of gully formation. Figure 2 illustrates the adopted sampling strategy. The ages of the uppermost sediment layers exposed in gully sidewalls provide maximum ages for erosion into those layers (i.e. deposition of those layers must have pre-dated the erosion). If present, the ages of any sediments within the gully floors ('channel fills') or the basal ages of any sediments deposited downslope of the gullies ('tributary fans') provide minimum ages for gully erosion (i.e. sediments have been derived from, and therefore must post-date, the erosion). Collectively, these maximum and minimum ages help to bracket the timing of initiation of erosion (Figure 2). The channel fills – some of which are up to several metres thick – also provide maximum ages for renewed erosion into the gully floors, while the uppermost tributary fan sediments provide minimum ages for this renewed erosion (Figure 2). Where available, other sources (e.g. aerial photographs, old farm plans, orthophoto maps and archaeological evidence within the gully floors) provided ancillary data to support gully age interpretations.[11]

At the sites, the stratigraphy and age of deeper sediments exposed in the lower to middle parts of gully sidewalls or in the banks of nearby incised rivers indicate that hillslopes and floodplains were relatively stable (i.e. non-eroding) features during most of the late Quaternary, with conditions typically alternating between sediment accumulation and soil development. At some point in the late Holocene, however, deep erosion became the dominant trend (Table 1). The maximum and minimum OSL ages show that initiation of erosion at each site significantly pre-dated the increasingly intensified livestock and arable farming that was associated with European incursion in South Africa's interior from the late 18th century onwards. Furthermore, although initiation of erosion at the study sites broadly coincides with the earlier arrival of Iron Age settlers in some parts of present-day South Africa (Table 1), it is unlikely that associated land-use changes at that time would have been sufficiently intense and widespread to have caused deep erosion across such a broad geographical area, especially in the more arid interior at sites like Erfkroon. Instead, available archaeological evidence from the Steelpoort region (e.g. foundations of rondavels, remnants of iron smelting) shows that Iron Age people were even living and working on the pre-existing, relatively flat, sheltered gully floors with their ready access to river water.[11]

In the absence of evidence for human causes of late Holocene gully erosion, other explanations must be sought. By comparing the OSL ages with various published southern African palaeoenvironmental data sets (e.g. derived from cave speleothems, lake cores, tree rings and marine cores), Lyons et al.[11] interpreted gully erosion as broadly coincident with abrupt climatic changes that occurred during the Medieval Climatic Anomaly (MCA, ~AD 900–1300) and Little Ice Age (LIA, ~AD 1300–1800). Erosion may have been triggered by abrupt hydroclimatic oscillations during the MCA and continued during the generally cool and dry LIA in response to large rainfall and flood events. This dramatic shift from long-term net sediment accumulation and soil development to sustained



Source: Image adapted from ©Lyons et al.[11] (reproduced under a CC BY 4.0 licence)

Figure 2: Schematic illustration of key landforms that may be associated with a gully or gully network ('donga'), with hypothetical optically stimulated luminescence (OSL) sample locations and the interpretations that can be derived (after Lyons et al.[7,11]). The age of a gully (i.e. timing of initial phase of erosion) is bracketed by the ages of the uppermost sediments on hillslopes or terraces (maximum ages), and the ages for channel fills within the gully and/or the basal ages for tributary fans downslope (minimum ages). The timing of any subsequent erosional phase is bracketed by the ages for channel fills within the gully (maximum ages) and the ages of the uppermost tributary fan sediments (minimum ages).

Table 1: Summary of the timings of gully erosion at the three study sites (after Lyons et al.[11]). Bracketing ages were derived principally from optically stimulated luminescence (OSL) dating of sediments associated with gullies, but minimum ages were supplemented by evidence of gullies on aerial photographs (Blood River, Moopetsi tributary) or early farm plans (Modder River).

Study site	Initiation of gully erosion (maximum and minimum ages)	Renewed phase of erosion (maximum and minimum ages)
Blood River	After ~1.62 ka but before ~0.89 ka (after ~AD 390 but before ~AD 1120)	After ~0.29 ka but before 0.076 ka (after ~AD 1720 but before AD 1935)
Modder River	After ~0.83 ka but before ~0.30 ka (after ~AD 1180 but before ~AD 1710)	After ~0.30 ka but before 0.109 ka (after ~AD 1710 but before AD 1903)
Moopetsi tributary	After ~2.7 ka but before ~0.22 ka (after ~BCE 690 but before ~AD 1790)	After ~0.22 ka but before 0.063 ka (after ~AD 1790 but before AD 1948)

deep erosion during and following the MCA-LIA likely involved the crossing of vegetation and geomorphic thresholds and positive feedbacks.[11] Fluctuations in vegetation cover resulting from hydroclimatic oscillations would have rendered land surfaces more susceptible to erosion, especially during abrupt dry–wet climatic changes when droughts and associated decreases in vegetation density and health would have been followed by increases in rainfall and floods. As gullies and channels deepened, more run-off and floodwater would be contained within, increasing water depths and bed shear stresses and thus further enhancing erosion.[11]

At some of the investigated sites, soil type and local base-level falls have exerted secondary controls on the specific locations, processes, rates and depths of gully erosion. For instance, marked soil textural contrasts along the Moopetsi tributary strongly control the erosional patterns, with gullies forming mainly along the western bank in soils derived from mafic lithologies of the Bushveld Complex, and many fewer located on the eastern banks in soils derived from the quartz-rich lithologies of the Transvaal Sequence (Figure 3). At Erfkroon, an initial ~15 m of incision occurred through the valley fill in response to climate changes, but the subsequent partial breaching of a dolerite sill exposed ~11 km downstream enabled an additional ~5 m of incision into bedrock.[11,12] At all the investigated sites, deep erosion is ongoing, but at rates slower than might be commonly assumed; aerial imagery from the 1930s onwards shows that, at the landscape scale, the dimensions of many gullies (e.g. lengths, widths) have barely changed over many decades (Figure 3).

Other findings and wider deployment of the investigative approach

Lyons et al.'s[11] findings complement some previous geomorphological, sedimentological and geochronological studies of alluvial and colluvial deposits exposed in gullies at other southern African locations.[13-15] For many sites, adoption of a longer-term, larger-scale 'geoscience perspective' helps to address the notion of an apparent rapid erosion problem, as it demonstrates that in many cases gully erosion is commonly a slower, oftentimes periodic, natural process linked to ongoing landscape denudation. One of Lyons et al.'s[11] key arguments is that, for sites where detailed investigations have yet to be undertaken, these findings challenge an often default assumption that gully erosion is *necessarily* attributable to human factors.

The emphasis on 'necessarily' in the previous sentence is important. A superficial reading of Lyons et al.[11] risks oversimplification of their argument, while a considered reading highlights some important caveats. For instance, there is acknowledgement that the South African (and wider southern African) land mass covers a broad geographical area and so encompasses a diversity of dryland climates, soil types, physiographies and land use histories, within which the relative importance of human (e.g. local land disturbance) and natural (e.g. regional climatic change) factors may differ. Indeed, Lyons et al.[11] explicitly address how, in some parts of South Africa, some studies have convincingly demonstrated clear links between land mismanagement and historical and more recent soil erosion, including gully formation.[4,5]

In recognition of these competing findings, the question posed in the main title of Lyons et al.[11] was deliberately open ended. So far, the number of sites investigated in detail is still trivial relative to the number of gullies so what about the relative importance of human and natural causes across other parts of the southern African interior? Wider deployment of Lyons et al.'s[11] investigative approach would help generate additional data sets that could contribute to answers. Along with investigations of new (previously unstudied) sites, revisiting sites where luminescence techniques have previously been employed successfully to date deeper (older) parts of sedimentary successions also might be productive; more focused sample collection for luminescence dating from the uppermost colluvial/alluvial layers and any channel fill or tributary fan deposits at locations like St Paul's Mission, the Okhombe valley and Voordrag[14-16] would generate additional data sets to enable wider spatial assessment of the relative importance of human and natural causes.

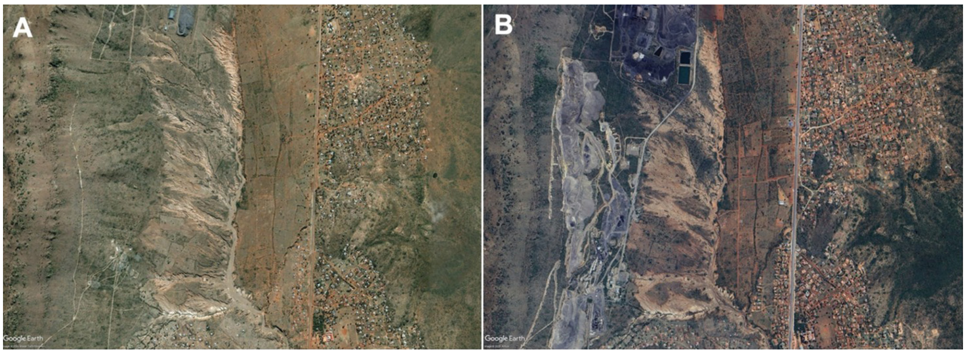
Reconciling competing explanations

Debates regarding the relative importance of human and natural causes of gully (and wider soil) erosion commonly become highly polarised; read in isolation, the open-ended question posed in the main title of Lyons et al.[11] (Are human activities or climate changes the main causes of soil erosion in the South African drylands?) could be taken as a perpetuating factor. In reality, 'human' and 'natural' causes are catch-all terms for various activities and factors that can interact in complex ways. In some areas of the interior, different human activities may be the dominant cause of erosion, while various natural factors may be the dominant cause elsewhere, but rarely do these two sets of factors operate independently. For instance, human and natural causes could be compounding: landscapes might be culturally primed but climatically driven, or climatically primed but culturally driven (cf. Macklin et al.[17]). Alternatively, the two sets of factors may be counteracting: for example, where rills and gullies are obliterated by deliberate ploughing, gully floor levelling or infilling for agriculture, or where gullies initiated on land cleared for agriculture naturally 'heal' through weather/climate-controlled vegetation regrowth.

In southern Africa, these types of interactions remain to be more fully investigated. Lyons et al.[11] briefly allude to the possibility of testing different hypothesised human–palaeoenvironmental interactions. They note that, in some areas, Iron Age land use (e.g. forest clearance) may have rendered landscapes more susceptible to erosion by other forcing factors (e.g. climate changes), or the reverse may have occurred, with Iron Age settlers arriving in landscapes primed for erosion by preceding climatic and wider environmental changes (see also Neumann et al.[18]).

Generating the geochronological and other data sets necessary to enable rigorous testing of such hypotheses in contemporary, historical and palaeoenvironmental contexts will require time, effort and resources. Detailed site-by-site and region-by-region investigations will be needed. But the potential benefits of improving knowledge of the causes, spatio-temporal patterns, and magnitudes of gully erosion are threefold.

First, just as the investigations of sites such as the Moopetsi tributary and the Modder River at Erfkroon have revealed the richness of interactions between a range of natural factors (e.g. climate change, soils, base-level



Sources: (A) Google Earth Image ©2025 Maxar Technologies; (B) Google Earth Image ©2025 Airbu

Figure 3: Aerial views of gullies along part of the Moopetsi tributary in: (A) June 2006 and (B) November 2023. The image width is 4.1 km and north is aligned to the top. Hillslopes converge from the west and east towards the tributary channel (image centre). During floods, flow in the channel is from north to south along the approximate contact between the Bushveld Complex lithologies (west) and the Transvaal Sequence lithologies (east). Note that most gullies have developed west of this lithological contact on mafic soils, and few gullies have formed east on quartz-rich soils. In the older image, most dwellings and roads are located in the east where there are few gullies, suggesting that, at this location, these types of human activities are not a main cause of gully erosion. The more recent image shows that increases in dwellings in the east and establishment of mine access roads in the west have led to no detectable gully network expansion. Mining operations in the last two decades have led to rapid, substantial earth material movement in the flanking mountain ranges, vastly outstripping the rates and volumes of gully erosion.

fall) in explaining the locations, processes, rates and depths of erosion, so might richer, more nuanced interpretations of contemporary erosion result from consideration of the interactions between a range of human and natural factors (e.g. Claasen et al.[19]). Palaeontological and archaeological investigations also would be enriched by greater consideration of the dynamic land surfaces upon which aspects of biological evolution and human cultural development have occurred.[2,3]

Second, more detailed consideration of gully erosion helps put contemporary land transformation in context. While gully and other forms of soil erosion have many deleterious on-site and off-site impacts, some other human activities (e.g. mining) are moving earth materials in greater volumes and at greater rates. In some cases, this ‘terraforming’ may be irreversibly damaging or removing key parts of the geoscience evidence base (Figure 3).

Third, a clear understanding of the causes of erosion, especially the relative importance of human and natural factors, is essential for the targeting of the limited resources available for erosion control and broader sustainable land management initiatives. Once gullies have been initiated and are actively eroding, they are very difficult to stabilise. Where human land use (e.g. ill-designed ploughing regimes, overgrazing, excessive burning) is indisputably causing new gullies or worsening existing gully erosion, the cessation of activities and erosion control efforts (e.g. revised land-use strategies and revegetation efforts) may have some chance of success.[1] But where gullies initially formed in response to natural factors occurring many decades or hundreds of years ago and are not now rapidly expanding, then erosion control efforts may be futile or worse. Lyons et al.[11] cite the example of gabion weirs in the Blood River dongas that have encouraged water retention (ponding) on duplex soils prone to dispersion and piping in the upper layers, so that water flow commonly occurs around the sides of the weirs and has resulted in localised donga widening; such weirs and other gully erosion control efforts (e.g. contour bank construction, run-off diversion, concrete check dams) are having similar impacts at other interior sites.[1] With the approach of the 20th anniversary of the United Nation’s International Year of Deserts and Desertification (2006), there is an opportunity to reflect critically on the targeting and effectiveness of erosion control and sustainable land management efforts, particularly in view of projected increases in climate variability and growing land-use pressures.

Conclusion

Recent decades have seen great advances in spatial data acquisition relating to soil erosion across the southern Africa interior; in particular, South Africa remains one of the few countries worldwide to have attempted a country-wide, systematic mapping of gully erosion.[20] We now also have many techniques for monitoring short-term gully growth[19], but temporal data acquisition relevant to advancing understanding of the age of gullies – essential for assessments of the relative importance of human and natural causes – has been far slower and limited to relatively few sites. Following Lyons et al.[11], wider deployment of investigative approaches that combine field, geochronology and archival data sets will help test hypotheses. A geoscience perspective on the gully erosion problem not only advances our understanding of Earth surface dynamics and human–landscape interactions but also has practical benefits for improved erosion control and sustainable land management efforts.

Acknowledgements

The data, concepts and arguments covered in this paper have been developed over a number of years, and have benefitted greatly from discussions with a number of colleagues worldwide, particularly Professor Terence S. McCarthy (School of Geosciences, University of the Witwatersrand). Over the years, support for the previously published research of myself and colleagues, as summarised within the Invited Commentary, has been provided by a number of sources, including Aberystwyth University, the University of the Witwatersrand, and the South African National Research Foundation.

Declarations

I have no competing interests to declare. I have no AI or LLM use to declare.

References

1. Olivier G, van de Wiel MJ, de Clercq WP. Intersecting views of gully erosion in South Africa. Earth Surf Process Landf. 2023;48:119–142. https://doi.org/10.1002/esp.5525

2. Churchill SE, Brink JS, Berger LR, Hutchison RA, Rossouw L, Stynder D, et al. Erfkroon: A new Florisian fossil locality from fluvial contexts in the western Free State, South Africa. S Afr J Sci. 2000;96:161–163.

3. Will M, Blessing M, Möller GHD, Msimanga L, Pehnert H, Riedesel S, et al. The Jojosi Dongas: An interdisciplinary project to study the evolution of human behaviour and landscapes in open-air contexts. South Afr Field Archaeol. 2024;19, Art. #3010. https://doi.org/10.36615/safa.19.3010.2024

4. Hoffman MT, Todd S, Ntshona Z, Turner S. Land degradation in South Africa. Pretoria: Department of Environment Affairs and Tourism; 1999.

5. Boardman J. How old are the gullies (dongas) of the Sneeuberg uplands, Eastern Karoo, South Africa? Catena. 2014;113:79–85. https://doi.org/10.1016/j.catena.2013.09.012

6. Rienks SM, Botha GA, Hughes JC. Some physical and chemical properties of sediments exposed in a gully (donga) in northern KwaZulu-Natal, South Africa and their relationship to the erodibility of the colluvial layers. Catena. 2000;39:11–31. https://doi.org/10.1016/S0341-8162(99)00082-X

7. Lyons R, Tooth S, Duller GA. Chronology and controls of donga (gully) formation in the upper Blood River catchment, KwaZulu-Natal, South Africa: Evidence for a climatic driver of erosion. The Holocene. 2013;23:1875–1887. https://doi.org/10.1177/0959683613508157

8. Tooth S, Brandt D, Hancox PJ, McCarthy TS. Geological controls on alluvial river behaviour: A comparative study of three rivers on the South African Highveld. J Afr Earth Sci. 2004;38:79–97. https://doi.org/10.1016/j.jafrearsci.2003.08.003

9. Tooth S, McCarthy TS, Rodnight H, Keen-Zebert A, Rowberry M, Brandt D. Late Holocene development of a major fluvial discontinuity in floodplain wetlands of the Blood River, eastern South Africa. Geomorphology. 2014; 205:128–141. https://doi.org/10.1016/j.geomorph.2011.12.045

10. Pulley S, Ellery WN, Lagesse JV, Schlegel PK, McNamara SJ. Gully erosion as a mechanism for wetland formation: An examination of two contrasting landscapes. Land Degrad Dev. 2018;29:1756–1767. https://doi.org/10.1002/ldr.2972

11. Lyons R, Tooth S, Duller GAT, McCarthy TS. Are human activities or climate changes the main causes of soil erosion in the South African drylands?: A palaeo-perspective from three sites in the interior. J Quat Sci. 2024;39:1116–1137. https://doi.org/10.1002/jqs.3651

12. Tooth S, Hancox PJ, Brandt D, McCarthy TS, Jacobs Z, Woodborne S. Controls on the genesis, sedimentary architecture, and preservation potential of dryland alluvial successions In stable continental interiors: Insights from the incising Modder River, South Africa. J Sediment Res. 2013;83:541–561. https://doi.org/10.2110/jsr.2013.46

13. Botha GA, Wintle AG, Vogel JC. Episodic late quaternary palaeogully erosion in northern KwaZulu-Natal, South Africa. Catena. 1994;23:327–340. https://doi.org/10.1016/0341-8162(94)90076-0

14. Botha GA. The geology and palaeopedology of late Quaternary colluvial sediments in northern KwaZulu/Natal. Memoir vol. 83. Pretoria: Council for Geoscience; 1996.

15. Temme AJAM, Baartman J, Botha GA, Veldkamp A, Jongmans AG, Wallinga J. Climate controls on late Pleistocene landscape evolution of the Okhombe valley, KwaZulu-Natal, South Africa. Geomorphology. 2008;99:280–295. https://doi.org/10.1016/j.geomorph.2007.11.006

16. Colarossi D, Duller GAT, Roberts HM, Tooth S, Botha GA. A comparison of multiple luminescence chronometers at Voordrag, South Africa. Quat Geochronol. 2020;60, Art. #101094. https://doi.org/10.1016/j.quageo.2020.101094

17. Macklin MG, Passmore DG, Rumsby BT. Climatic and cultural signals in Holocene alluvial sequences: The Tyne Basin, Northern England. In: Needham S, Macklin MG, editors. Alluvial archaeology in Britain. Oxbow Monograph 27. Oxford: Oxbow Press; 1992. p. 123–140.

18. Neumann FH, Scott L, Bousman CB, van As L. A Holocene sequence of vegetation change at Lake Eteza, coastal KwaZulu-Natal, South Africa. Rev Palaeobot Palynoly. 2010;162:39–53. https://doi.org/10.1016/j.revpalbo.2010.05.001

19. Claasen D, Botha G, Linol B. An integrated assessment of erosion drivers facilitating gully expansion rates – a near century multi-temporal analysis from South Africa. Land Degrad Dev. 2024;35:3675–3699. https://doi.org/10.1002/ldr.5161

20. Mararakanye N, Le Roux JJ. Gully location mapping at a national scale for South Africa. S Afr Geogr J. 2012;94:208–218. https://doi.org/10.1080/03736245.2012.742786