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Palaeo-perspectives on anthropogenic soil loss and landscape resilience: an introduction

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Abstract

This paper provides an introduction and context for a series of empirical-historical case studies in a joint Virtual Special Issue (VSI) of Geoarchaeology and Journal of Quaternary Science that offer a palaeo-perspective on anthropogenic soil loss and landscape resilience. The articles cover a range of different environments and timescales, and seek to address the overarching question of how much erosion has been accelerated due to human action. They potentially allow the identification of a pre-disturbance baseline on which a subsequent increase of anthropogenic causation was superimposed. In several cases, this onset – along with associated actions to conserve soil (e.g. via agrarian terrace construction) - can traced back to around 4000 years ago.

How fast is Planet Earth being eroded? How much of this erosion is 'natural', and how much has it accelerated due to human action? More than a century ago, Sherlock (1922) claimed that the amount of sediment moved by humankind exceeded that of any other geomorphic agent. But was he right? The question has been much debated in the years since then (Hooke 2000, Syvitski et al. 2005, Wilkinson 2005, Giusan et al. 2017). Alongside numerical modelling, two principal empirical approaches have been adopted in attempts to answer this question. The first involves the measurement of contemporary rates of sediment flux (i.e., sediment transport) via different agencies. Flux of sediment reflects landscape stability and instability, whether of climatic, tectonic or human origin, or some combination. Transporting agencies include glacier ice and the wind (mainly aeolian dust), but globally, the dominant means of sediment movement from land to sea is via rivers, as suspended or dissolved load (Gibbs 1970; Douglas 1990). Studies have ranged in spatial scale from measurement of experimental soil erosion plots under different land cover types (e.g. Rapp 1975), through small catchment monitoring (Boardman et al. 1990), to analysis of sediment discharge from major river basins like the Yangtse and Ganges (Walling and Webb 1983; Summerfield and Hulton 1994). The alternative approach is historical, commonly involving the examination of sedimentary 'archives' in lakes, river valleys and estuaries to establish

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longer-term rates of change. The papers in this joint Virtual Special Issue (VSI) of Geoarchaeology and Journal of Quaternary Science adopt this second strategy via a series of empirical-historical case studies that cover a range of different environments and timescales (Table 1). It is an approach based on the assumption that at some point in the past, human impact on erosion rates was minimal relative to natural agencies, and that this provides a baseline for assessing any subsequent increase of anthropogenic causation. In regions such as Europe and South Asia, this baseline is believed to date to mid-Holocene times, whereas it continued into the late Holocene in areas such as temperate North America (Van Vliet-Lanoë et al. 1992; Dearing and Jones 2003; Hoffmann et al. 2010).

While a shared theme underpins this joint special issue, that of soil erosion, and the study of the complex interplay between climate and anthropogenic mechanisms, the allocation or “badging” of articles as either Geoarchaeology or Journal of Quaternary Science was based on the extent to which colleagues explicitly engaged with archaeological phenomena in their studies. For example, von Zon et al.’s (2025) assessment of the role of Roman road networks in altering erosion dynamics in the Gete catchment, Belgium, or the two papers that review recent geoarchaeological approaches in the study of terraces, Brown et al. (2025) and Kinnaird et al. (2025).

The sustainability of anthromes (anthropogenic biomes) for human use depends on maintaining soil and ecosystem functions, and these have often been threatened by mismanagement and landscape degradation. Soil erosion, for example, affects not only upstream source areas but also downstream zones of sediment deposition in valley bottoms and via coastal progradation. Storage of sediment in “sinks” such as basal hillslope colluvium represents an important methodological impediment to scaling up micro-scale studies to larger river basin flux rates, as Trimble (2009) showed for small tributaries of the Mississippi. Alluvial stratigraphies have revealed how overbank sedimentation in the Mid-West USA increased historically linked to agricultural intensification, including several major increments of deposition from large floods (Knox 2006). Lowland regions such as this typically had relatively low natural denudation sites, and land-use conversion to cropland often increased erosion by at least an order of magnitude, but much of this eroded soil failed to enter downstream river systems. Observations about denudation rates are thus scale-dependent, and sediment yields derived from small erosion plots cannot be applied to sub-continental drainage basins (and vice-versa). Soil erosion can also permanently alter the potential natural and agro-ecosystems that emerge during subsequent periods of landscape recovery. The uplands of southern Anatolia, for example, saw a switch in forest composition during the late Holocene, with pine trees becoming dominant during early Medieval reforestation. This followed a period of cultural land use in antiquity, the

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Beyşehir Occupation phase, during which erosion permanently altered soil conditions, favouring pine relative to other tree taxa (Roberts 1990; van Loo et al. 2017).

Geomorphological environments which record soil erosion histories can be divided into those of net erosion and those of net deposition. The former ought to provide the more accurate soil loss data, but on their own, degraded hillslopes are an unreliable guide to erosion history. Their mere existence provides no clue about the age or origin of erosion, and this has given rise to long-standing debates, such as discussions about the causes of gully (arroyo) incision in regions such as the American southwest (Cooke and Reeves 1976). A southern African equivalent is provided by the question of the origin of dongas (incised gullies), the subject of critical evaluation by Lyons et al. (2024; this VSI). They used OSL dating to show that incision at three sites preceded European settlement and land-use conversion. Rather, they argue that gully initiation was triggered by alternating droughts and floods linked to climate changes during the millennium prior to the 19th century. The need for accurate dating underpins all attempts at reconstructing historical changes in sediment flux, including those focused on the point of deposition, where sediment yield is used as a surrogate for soil loss. Ideally, this should involve not only accumulation rates in a single section or core, but laterally to allow three-dimensional volumetric calculations. For quantitative reconstructions using sedimentary records, it is best to use relatively small, 'closed' catchments such as lake drainage basins with a high trap efficiency (Dearing 1994). Two of the studies in this VSI involve lake basins, one a study from Mexico (Aguilera Lara and Metcalfe 2025), the other in Malaysia (McGowan et al. 2025). The former involves a comparison of two lake basins within the highlands of Michoacá, one of which was known to have suffered land degradation and erosion, while the other is considered to be relatively undisturbed. In fact, palaeolimnological research shows that, even at the time of the Spanish conquest, neither was pristine, due to pre-Hispanic landscape disturbance. The latter study of a small tropical wetland in peninsular Malaysia takes a shorter time frame, focussing on organic carbon flux, whose sources shifted following forest clearance in the 1940s and subsequent plantation of rubber and palm oil trees. Both studies have been able to make use of historical archives that record landscape changes, and they contribute a long-term perspective to current debates over sustainability and conservation.

Unlike lakes, river valleys do not represent closed sedimentary systems, with much of the eroded soil and substrate being exported, thus making historical sediment budgets harder to calculate. On the other side, river valleys are widespread in the landscape and have been the locus of human settlement, now and in the past. In a pair of coupled articles in this VSI, Hoevers et al. (2024) and von Zon et al. (2025) report the results of investigations into the Holocene history of land cover and floodplain geoecology in Belgium's loess belt and sandy Campine regions, which can be linked to variations in human impacts, notably via changes in land cover. These studies exploit the potential

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of multi-proxy data sources, including pollen, testate amoebae and stable isotopes to reconstruct causal factors and response variables within the same catchments. Another important contribution of palaeo-science has been to show how sediment sources typically shifted during the Holocene from bedrock to topsoil derivation, using sediment tracing methods such as mineral magnetics (Thompson and Oldfield 1986). In many environments, this is an effective way of testing Sherlock's (1922) assertion, by separating material denuded by natural processes from those added by human actions.

Further south, the Mediterranean basin has long been the subject of debate about the causes of the historical erosion. The existence of at least one major cycle of alluvial infilling and incision during the late Holocene was demonstrated by Claudio Vita-Finzi in his seminal "Mediterranean Valleys" book (1969) and is the subject of a re-evaluation in this VSI by Bintliff (2025). Vita-Finzi believed that these hydro-geomorphogical changes were caused primarily by post-Roman climatic variations, whereas others (e.g., Wagstaff 1981) argued for primarily human causation. In a synthesis of records from different Mediterranean regions, Walsh et al. (2019) showed that overall rates of sediment flux increased substantially during the last four millennia, coincident with increases in human population and a decrease in woodland cover. While this is consistent with anthropogenic causation, alluviation did not increase linearly but alternated over time, in line with Vita-FInzi's model. The timing of valley sedimentation and incision phases may therefore have been determined primarily by prevailing climatic conditions, acting as a pacemaker. Bini et al (2025) exploit the potential of the fact that river valleys are often spatially congruent with rich archaeological field evidence to reconstruct the complex history of river channel avulsion between Lucca and Pisa in west central Italy. Comparison with nearby cave speleothem records shows that a major flood phase during the 1st century CE coincided with a period of wetter climate in this region. Berger and Brochier (2025) also report the history of a river debouching into the Mediterranean Sea, in this case the Rhône, which straddles the divide between temperate, alpine and Mediterranean zones. Like Bini et al. (2025), they were able to exploit geoarchaeological field evidence, in this case uncovered during construction work for the high-speed TGV rail line. This has produced detailed and well-dated cross-sections through river alluvium, interbedded with colluvium and buried soils, showing multiple alternating phases of sedimentation and landscape stabilisation during the mid-late Holocene. Thus, it seems that both human and climatic factors played a part in changes in fluvial sediment flux, the former often acting as an ultimate cause, the latter as a proximal one.

Human land conversion, notably from forest to farmland, has reduced rainfall interception and increased the potential for soil particle entrainment. At the same time, people have a strong incentive to conserve soil, especially in agricultural terrain, and

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many landscapes are littered with evidence for past soil conservation, notably via agricultural terraces, as highlighted in this VSI by Brown et al. (2025) and Kinnaird et al. (2025). These culturally created landscapes have a long history and continued potential for future sustainable development. OSL dating shows that terrace construction and re-building did not always occur at times expected from historical narratives, highlighting how rural economies could sometimes function independently of urban centres and wider polities.

Palaeo-scientific research has highlighted the complex historical interaction between human and natural agencies in altering Hutton’s rock cycle. It has also pointed to mechanisms that may not be evident in studies based on monitoring and measurement of contemporary processes alone. The ergodic approach, for instance, in which space is substituted for time, fails to capture the significance of short-lived phases of landscape instability during transitions between one land cover regime and another. This was demonstrated 50 years ago by Margaret Bryan Davis in her classic (1976) study of Frains Lake in the US Midwest, which revealed how the ploughing up of woodland in the mid-19th century led to positive feedback and landscape instability, before the system eventually stabilised at a new, but higher level of sediment flux. Palaeo studies such as this consequently make it possible to establish the time taken for system recovery following disturbance. At Nar Lake in central Anatolia, whose sediments are annually laminated, Roberts et al. (2019) were able to show that erosion rates fell back to pre-disturbance levels within a few decades after land abandonment and rewilding in the late 7th century CE. Records such as this therefore offer hope for the future, by telling us that many human-degraded landscapes are capable of self-healing. This has repercussions for how palaeoenvironmental sciences, including geoarchaeology, can contribute to contemporary debates on landscape management and the mitigation of changing climates and agricultural practices. As von Zon et al. (2025) suggest, the variation in the timing (or lag) in the response of geomorphic systems to different forms of perturbation has implications for when and how societies intervene and what baseline environment they are aiming to recreate and protect. If we accept that agricultural terraces constitute one of the most significant forms of anthropogenic erosion mitigation practices, a key question for contemporary landscape managers is how or even if terrace systems should be preserved in landscapes where agriculture has waned or is no longer practised. Such questions have repercussions for the design of research projects and methodologies; specifically, the need to incorporate catchment-based studies of alluvial systems and erosion with studies of agricultural landscapes/slopes and colluvial systems to interrogate evidence for breaks in the sedimentary record due to positive human mitigation.

Finally, we can return to a key question posed earlier in this paper, namely, at one point in time do palaeoenvironmental and geoarchaeological data indicate that an upward

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shift in the rate of soil loss occurred? In other words, can we identify regional thresholds in landscape stability when anthropogenic activities raised erosion rates outside the envelope of the long-term geological norm? In the empirical studies presented in this VSI, it is clear that the mid-late Holocene transition (i.e., the start of the Meghalayan around 4000 years ago) represents a key tipping point in many regions of both Old and New Worlds. In western Europe, sediment discharge and flooding within the catchment of the river Rhône, began to depart from the previous, relatively stable trajectory around 2500 BCE (Berger and Brochier 2025), while in Belgium's loess belt, a comparable shift took place from ~1900 BCE (Hoevers et al 2024). In the highlands of Mexico, lake basin records similarly show evidence of anthropogenic disturbance of erosion regimes from at least 1500 BCE (Aguilera Lara and Metcalfe 2025). Significantly, the 2nd millennium BCE also marks some of the earliest definitive dates in Europe for the construction of agricultural terraces designed to conserve soil and moisture, in locations ranging from Britain to the Aegean (Brown et al. 2025). Thus, human-induced acceleration of soil loss and measures to counteract this can be detected at a regional scale back to Bronze Age times (or their equivalent) in at least some parts of the world. If this can be considered as a mark of a regional Anthropocene, then its onset can be traced back in time well before the mid-20th century "Great Acceleration" (Steffen et al., 2015).

References

Aguilera Lara, J. and Metcalfe, S.E. 2025 Exploring soil erosion in the lake basins of Michoacán, Mexico: from sediment cores to conservation policies. Journal of Quaternary Science, 40, 671-683.

Berger, J.F. and Brochier, J.L. 2025 Past hydro-pedological events and trend reflected in the Mid–Late Holocene alluvial record of the Middle Rhône Valley and tributaries: A new reference for South East France. Journal of Quaternary Science, 40, 711-733.

Bini, M., Caroti, A., Cantini, F., Fabiani, F., Fiorentini, M., Fornaciari, A., Isola, I., Lazzarotti, M., Luppichini, M., Mensing, S. and Palli, J. 2025 The Paleo-Serchio River: history of floods between Lucca and Pisa during the Roman period. Journal of Quaternary Science, 40, 141-152.

Bintliff, J., 2025 The Mediterranean Valleys revisited. Geoarchaeology, 40, p.e22029.

Boardman, J., Foster, I.D.L. and Dearing, J. A. (eds) 1990 Soil erosion on agricultural land. British Geomorphological Research Group, Symposia Series. Wiley, Chichester.

Brown, A.G., Pears, B., Cucchiaro, S., Tarolli, P., Lang, A., Zhao, P., Walsh, K., Van Ost, K., Albert, R.M., Alonso-Eguiluz, M. and Vokotopoulos, L., 2025 The Geoarchaeology of

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Agricultural Terraces in Europe: Construction, Resilience and Implications for sediment delivery. Geoarchaeology, 40, p.e70008.

Cooke, R.U. and Reeves, R.W. 1976 Arroyos and environmental change in the American South-West. Clarendon Press, Oxford.

Davis, M.B. 1976 Erosion rates and land use history in southern Michigan, Environmental Conservation, 3, 139-48.

Dearing, J. 1994 Reconstructing the history of soil erosion. In Roberts, N. (ed.) The changing global environment. Blackwell, Oxford. pp.242-261.

Dearing, J.A. and Jones, R.T. 2003 Coupling temporal and spatial dimensions of global sediment flux through lake and marine sediment records, Global and Planetary Change, 39, 147-168.

Douglas, I. 1990 Sediment transfer and siltation. In Turner, B.L. et al. (eds) The Earth as transformed by human action. Cambridge University Press, Cambridge, pp. 215-234

Gibbs, R. 1970 Mechanisms controlling world water chemistry. Science 170, 1088-90.

Giosan, L., Ponton, C., Usman, M., Blusztajn, J., Fuller, D.Q., Galy, V., Haghipour, N., Johnson, J.E., McIntyre, C., Wacker, L. and Eglinton, T.I., 2017 Massive erosion in monsoonal central India linked to late Holocene land cover degradation. Earth Surface Dynamics, 5, 781-789.

Hoevers, R., Broothaerts, N. and Verstraeten, G. 2024 Holocene geoecohydrological floodplain dynamics in NE Belgium: regional drivers of local change. Journal of Quaternary Science, 39, 781-800.

Hoffmann, T., Thorndycraft, V.R., Brown, A.G., Coulthard, T.J., Damnati, B., Kale, V.S., Middelkoop, H., Notebaert, B. and Walling, D.E. 2010 Human impact on fluvial regimes and sediment flux during the Holocene: review and future research agenda. Global and Planetary Change 72, 87-98.

Hooke, R.L. 2000 On the history of humans as geomorphic agents. Geology 28, 843–846.

Kinnaird, T.C., Abellán Santisteban, J., Brandolini, F., Carlton, R., Carrer, F., Civantos, J.M.M., Duggan, M., Holcomb, J.A., Lekakis, S., Ramos Rodríguez, B. and Salazar Ortiz, N. 2025 Unearthing the histories of agrarian landscapes: a research framework for terraces as sustainable environments. Geoarchaeology, 40, p.e70004.

Knox, J.C. 2006 Floodplain sedimentation in the Upper Mississippi Valley: Natural versus human accelerated. Geomorphology 79, 286–310.

Lyons, R., Tooth, S., Duller, G.A. and McCarthy, T. 2024 Are human activities or climate changes the main causes of soil erosion in the South African drylands? A palaeo-

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perspective from three sites in the interior. Journal of Quaternary Science, 39, 1116-1137.

McGowan, S., Lacey, J.H., Engels, S., Boyle, J., Briddon, C., Leng, M.J., Moorhouse, H.L., Panizzo, V. and Shafiq, M. 2025 Land use, hydroclimate and damming influence organic carbon sedimentation in a flood pulse wetland, Malaysia. Journal of Quaternary Science, 40, 657-670.

Milliman, J.D. 1990 Fluvial sediment in coastal seas: flux and fate. Nature and Resources 26, 12–22.

Rapp, A., 1975. Soil erosion and sedimentation in Tanzania and Lesotho. Ambio 4,154-163.

Roberts, N. 1990 Human-induced landscape change in south and south-west Turkey during the later Holocene. In Bottema, S., Entjes-Nieborg, G. and van Zeist, W. (eds) Man's role in the shaping of the Eastern Mediterranean landscape. A.A. Balkema, Rotterdam, pp.53-67.

Roberts, N., Allcock, S.L., Barnett, H., Mather, A., Eastwood, W.J., Jones, M., Primmer, N., Yiğitbaşıoğlu, H., and Vannière, B. 2019. Cause-and-effect in Mediterranean erosion: The role of humans and climate upon Holocene sediment flux into a central Anatolian lake catchment. Geomorphology 331, 36-48.

Sherlock, R.L. 1922 Man as a geological agent. London.

Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O. and Ludwig, C. 2015 The trajectory of the Anthropocene: The Great Acceleration. The Anthropocene Review 2, 81–98.

Summerfield, M.A. and Hulton, N.J. 1994 Natural controls of fluvial denudation rates in major world drainage basins. Journal of Geophysical Research 99, 13,871-83

Syvitski, J.P., Vörösmarty, C.J., Kettner, A.J. and Green, P. 2005 Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308, 376–380.

Thompson, R. and Oldfield, F. 1986 Environmental magnetism. George Allen and Unwin. London.

Trimble, S. 2009 Fluvial processes, morphology and sediment budgets in the Coon Creek Basin, WI, USA, 1975–1993. Geomorphology 108, 8–23

van Loo, M., Dusar, B., Verstraeten, G., Renssen, H., Notebaert, B., D'Haen, K. and Bakker, J. 2017 Human induced soil erosion and the implications on crop yield in a small mountainous Mediterranean catchment (SW-Turkey). Catena, 149, 491-504.

van Vliet-Lanoë, B., Helluin, M., Pellerin, J. and Valadas, B. 1992 Soil erosion in Western Europe: from the last interglacial to the present. In Bel, M. and Boardman, J. (eds) Past and Present Soil Erosion, Oxbow books, Oxford. pp. 101–114.

van Zon, M., Hoevers, R., Swinnen, W., Simons, B., Vanmontfort, B. and Verstraeten, G. 2025 Holocene floodplain transformation through catchment-scale human-environment interactions: an interdisciplinary case study of the Gete catchment (Belgium). Geoarchaeology, 40, p.e22026

Vita-Finzi, C. 1969 The Mediterranean Valleys. Geological Changes in Historical Times. Cambridge University Press, Cambridge.

Wagstaff, J. M. 1981 Buried assumptions: Some problems in the interpretation of the "Younger Fill" raised by recent data from Greece. Journal of Archaeological Science, 8, 247-264.

Walling, D.E. and Webb, B.W. 1983 Patterns of sediment yield. In K.J. Gregory (ed.) Background to palaeohydrology. Wiley, Chichester, pp.69-100.

Walsh, K., Berger, J-F., Roberts, N., Vannière, B., Ghilardi, M., Brown, A.G., Woodbridge, J., Lespez, L., Estrany, J., Glais, A., Palmisano, A., Finné, M., Verstraeten, G. 2019 Holocene demographic fluctuations, climate and erosion in the Mediterranean: a meta data-analysis. The Holocene 29, 864-885.

Wilkinson, B.H. 2005 Humans as geologic agents: a deep-time perspective, Geology 33, 161-164.