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Baobabs, Monsoons, and Tsunamis: Exploring the Hidden Landscapes of the Ancient Swahili Coast with Geospatial Data and Technologies

Wolfgang Alders

In fall 2025, I joined the Cotsen Institute as a lecturer, teaching a course called Geographic Information Systems for Archaeology and Cultural Resource Management. The class focused on hands-on training in the analysis and visualization of archaeological spatial data using ESRI ArcGIS Pro. It also introduced students to the vast ecosystem of open-access, free, and low-cost geospatial data in online databases and web portals. Starting as a niche experimental method in the 1980s, geospatial archaeology (which includes software-based geographic information systems [GIS]; satellite, aerial, and terrestrial remote sensing; and high-density digital survey and measurement tools like lidar, photogrammetry, and laser scanning) has matured through several phases of exponential growth to become a well-established subfield (Ullah et al. 2024). This has coincided with the expansion of geospatial science more broadly and the increasing availability of free, open-access geospatial data and resources. There has also been a vast proliferation of methods and tool kits for visualizing and analyzing data, as well as a deep reserve of expertise spread across online forums and communities to address nearly any geospatial problem.

A lot of my work as a landscape archaeologist has focused on finding geographic, environmental, and historical spatial data within this ecosystem and combining it in unique ways to address relevant archaeological questions. This approach was born out of necessity. I am an archaeologist working in the tropical environments of coastal eastern Africa, a region called the Swahili Coast (**fig. 1**), studying how communities there have adapted to environmental change and sociopolitical transformations. Over the past 2,000 years, coastal groups have created a vibrant, interconnected, urban mercantile society that has facilitated long-distance economic exchanges across the Indian Ocean in the process. Although this pivotal region links Africa to the world, the large-scale environmental and anthropogenic legacies of Swahili society remain relatively unexplored.



Figure 1. View of Tongoni, on the northern Tanzanian section of the Swahili Coast. The gray stone ruins (center, foreground) were the monumental mosque and tomb complex of the medieval town. Photo by Ioana Dumitru, 2024.

When I started work there during graduate school, I quickly realized that the transformative geospatial methods used in places like the Levant and the American Southwest were not so applicable. The Swahili Coast has a number of characteristics that limit the use of traditional methods in archaeological GIS and remote sensing: (1) a rainy tropical environment that produces dense vegetation and cloudy conditions, limiting site visibility in satellite imagery; (2) little monumental architecture or large-scale settlements built of permanent materials visible from space; (3) anthropogenic landscape modifications that are primarily vegetal rather than topographic (with very little topographic differentiation in general; most of the coast is a flat, low-lying plain); and (4) significant interdigitation of archaeological sites within modern towns, cities, and agricultural space. The challenges these characteristics pose for archaeologists interested in large-scale regional analysis with GIS and satellite remote sensing has meant that we are probably underestimating the scale and diversity of settlement in this region and the extent of landscape-scale anthropogenic transformations. This has undervalued the significance of this pivotal zone, which linked vast parts of East Africa to the Indian Ocean world during phases of early globalization, from antiquity to the nineteenth century.

Researchers have noticed this limitation. A perennially cited paper is Fleisher and LaViolette's article (Fleisher and LaViolette 1999) on detecting the "hidden majority" in Swahili contexts, an ethnoarchaeological study that tracked the decomposition of a modern Swahili wattle-and-daub house over only five years. Showing how quickly this form of common vernacular architecture degrades in the tropical climate and becomes almost invisible archaeologically, the authors argued that researchers were underestimating the extent and diversity of ancient Swahili villages, towns, and cities, given that most studies up until then had focused on only the small handful of monumental, stone-built ruins that occupied the elite centers of Swahili settlements. In the years since, researchers have increasingly investigated landscapes beyond the stone-built cores of Swahili cities, turning up evidence for craft, industry, long-distance trade, religious practice, maritime technologies, and the management of a broad spectrum of diverse resources from approximately the eighth century AD onward. Still, researchers have lacked the funding and labor to conduct fieldwork to identify these newly recognized

settlement forms, since surveys often require intensive shovel-test pit grids and test units (**fig. 2**) to unearth deeply buried ancient wattle-and-daub architecture.

Despite the challenging characteristics of the eastern African coast, combined geospatial methods may help unearth the legacies of ancient Swahili settlement patterns, adaptations, and anthropogenic activities at a large regional scale. Since earning my PhD, I have experimented with techniques that combine environmental, historical, geographic, and topographic data in unique ways to better understand ancient Swahili landscape change.



Figure 2. Excavating part of an ancient wattle-anddaub structure in modern banana plantations in Zanzibar, 2024, with the author (left) and Hadija Fakhi Hamadi (right), a heritage officer in the Zanzibar Department of Museums and Antiquities. Photo by Hamad Suleiman.

For instance, in Zanzibar, Tanzania, I combined environmental data on hydrogeology and soil infiltration from a study on malaria transmission (Hardy et al. 2015) with land use data from the European Space Agency's Sentinel-2 WorldCover database; slope, aspect, and elevation data from the Shuttle Radar Topography Mission (SRTM); coral reef data from the Tanzania Sensitivity Atlas; soil type data from the Zanzibar Department of Rural and Urban Planning (Khamis et al. 2017); rainfall data (Colbert et al. 1987); and digitized features of a 1907 map of the island (Khan Bahadur 1907) that depicts streams, caves, wells, villages, and roads. Using a tool in QGIS called zonal statistics, I divided these environmental datasets into zones and weighted them by comparing them to the distribution of settlements on the 1907 map.

The result (Alders 2023b) was a high-resolution model that accurately predicted the location of Zanzibar's well-known precolonial towns, such as the port of Unguja Ukuu (eighth–tenth centuries AD), where researchers recently found a rock crystal seal ring inscribed with the Arabic word lillah (Sarathi et al. 2022), and Kizimkazi, the site of eastern Africa's oldest continuously used mosque, which has an inscription dating its construction to AD 1187 (Kleppe 2001). The model also accurately predicted the locations of smaller rural village sites that I had identified in surveys in 2019, the first discovery of rural agricultural villages (eleventh–fifteenth centuries AD) inland on the island, in zones that became plantations in the nineteenth century (Alders 2023a). This method contributes to an understanding of the environmental affordances that structured long-term settlement change on the Swahili Coast and provides a baseline for heritage conservation and future prospection (**fig. 3**) using open-access software and freely available datasets.

Another way to investigate Swahili landscapes is through satellite remote sensing. With researchers from Columbia University and Syracuse University, I authored a paper exploring the ways that multispectral (perceiving more than the visible wavelengths of light), multitemporal satellite data (images of the same area taken over multiple seasons) can be used to investigate landscape palimpsests, define anthropogenic activities, and delineate field systems in tropical environments, where dense vegetation has traditionally limited visibility (Alders et al. 2024). For the last seven years, PlanetScope satellites have started near-daily imaging of parts of the earth's surface, making multitemporal, multispectral, 3 m pixel imagery accessible to researchers. We applied composites of this imagery to landscapes across three Indian Ocean islands—Zanzibar, Mauritius, and Madagascar—and showed how the multispectral, multitemporal characteristics of this data can be used to draw out and quantify the subtle traces of anthropogenic modification to vegetated landscapes, which even lidar might fail to detect.



Figure 3. Ruined mihrab of a fifteenth/sixteenth-century mosque built of Porites coral in southwest Zanzibar at the site of Kiwani Vee, recorded during surveys in 2023. Photo by the author.



Figure 4. A recently burned field plot in Zanzibar's eastern region, where farmers have developed methods for planting in extremely rocky soils over hundreds of years. Photo by the author.

For instance, multispectral imagery drawn from multiple seasons can be used to distinguish and quantify the extent of shifting cultivation (**figs. 4 and 5**) and field construction in Zanzibar's eastern region, a place long characterized as marginal, "natural," and wild

compared to the cultivated plantation zones of the west. This research, combined with surveys and oral history, has shed light on the way that Indigenous Swahili agricultural adaptations like kupiga makongo (cutting into limestone bedrock to conserve soils for planting) and swidden cultivation have shaped terrestrial landscapes for at least 1,000 years. I have also tried to address the problem of significant interdigitation between the Swahili archaeological record and modern urban land use by using similar multispectral satellite scenes to identify regions where rapid urban changes are obscuring, or threatening to obscure, areas of archaeological potential around the ancient core of Zanzibar Stone Town (Alders 2024). These models helped me stratify and plan surveys in the city's rural hinterland in 2023 and 2024, uncovering evidence for small rural nodes that were nevertheless connected to Indian Ocean trade networks as far back as the eighth century AD.

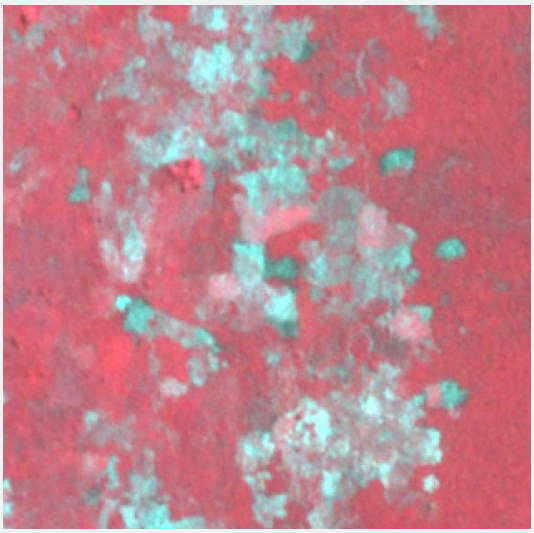

Figure 5. False color image of swidden field plots in Zanzibar's eastern region, used to highlight spectral differences. Red areas are vegetated. Gray and blue areas are field plots that are in use. The darker the blue, the more recently the field plot was opened and burned.

While most parts of the Swahili Coast do not exhibit large-scale landscape engineering in the form of earthworks, canals, or terracing, coordinated human activities still leave their mark on the vegetal record. Baobab trees (*Adansonia digitata*) are a particularly significant example (**fig. 6**). They are a crucial resource for thousands of communities across Africa today. All parts of the tree have important uses, for food, medicine, forage, cordage, cloth, mats, glue, soap, and fuel. Furthermore, many baobabs function as cultural landmarks and ritual venues. Baobab trees appear to be propagated through human activities and are strongly associated with archaeological sites. Thus their distribution may be an enduring and overlooked Anthropocene legacy within African landscapes. However, they are increasingly threatened by rapid urbanization and intensifying land use in some regions. Climate changes leading to droughts may also be impacting baobab populations, though this remains an ongoing debate (Venter and Witkowski 2024). Baobab resources are an important hedge against crop failure during droughts, so their loss exacerbates climate-induced insecurity, especially for rural communities.



Figure 6. The author, inside a large hollow baobab tree in Zanzibar in 2024. Photo by Khamis Sheha Haji.

Efforts to conserve and understand human–baobab entanglements are stymied by a lack of large-scale, high-resolution data. To address this, I worked with Jonathan Lim (University of Arkansas) and Logan Brunner (University of Canterbury) to map baobab tree distributions in Zanzibar, using free, open-access, high-resolution drone imagery. Mapping baobabs can contribute to long-term archaeological understandings of Anthropocene entanglements while simultaneously aiding ecosystem conservation and sustainable community resource management. We published this research in the *Journal of Archaeological Science* (Alders et al. 2025). You can also read about it on The Conversation.[1]

Now, as a codirector of the Dynamic Coasts and Landscapes of Resilience (CALOR) project in northern Tanzania, I am trying to bring all these methods together. Codirectors Ioana Dumitru (University of Sydney) and Elinaza Mjema (University of Dar Es Salaam [UDSM]) and I are combining satellite remote sensing, predictive modeling, soil science, archaeological survey and excavation, and community engagement to investigate the deep history of Swahili adaptations to climate extremes, monsoonal flooding, and natural disasters at the interface of the Pangani River system and the Indian Ocean over the last 2,000 years in northern Tanzania. The project explores the intersection of elite formation, collective action, and the management of environmental crises like monsoonal flooding, drought, and, notably, a tenth-century tsunami that buried the village of Kimu on the banks of the Pangani River (Mjema 2018).



Figure 7. Surveying along the Pangani River can get quite muddy! Left to right: the author, Hilda Lelio (UDSM), and Mugasire Kisoma (UDSM). Photo by Ioana Dumitru.



Figure 8. Earthenware pottery from surveys on the Pangani River in 2024. Photo by the author.

In 2024 we completed a systematic drone lidar survey, mapping the river mouth and bay across 80 ha with the help of Cotsen IDP alum Jacob Bongers. Our goals were to map existing archaeological sites in high resolution, detect new sites beneath dense vegetation, and model terrain to simulate flooding events related to monsoonal climate patterns and the tenth-century tsunami (**fig. 7**). With high-resolution terrain models derived from lidar, we will be able to explore water levels of extreme flood events to evaluate how they would have impacted other settlements upriver.

By comparing these models with archaeological data (**fig.8**) related to subsistence, craft, exchange, and settlement reorganization, it will be possible to evaluate how coastal communities adapted and built resilient frameworks in response to extreme weather events and climate change over the past two millennia. This will also provide data to aid in conserving agricultural land and heritage resources with communities in the present. Tanzania is disproportionately impacted by climate change, experiencing significant coastal flooding during the rainy season. Our work seeks to create ethical partnerships with stakeholders in Pangani to produce knowledge about climate resilience and disaster management from a long-term perspective.

Like the earlier predictive modeling in Zanzibar, CALOR is also leveraging the vast quantity and diversity of geospatial and environmental datasets that are now available for use. For instance, we are experimenting with bathymetry (GEBCO), sea level rise projections (IPCC AR6 and NASA Sea Level Change Portal), land use data (ESA WorldCover 10 m), geology (USGS and OneGeology), meteorological data (NOAA and ERA5 climate reanalysis), coral reef and kelp distributions (UNEP-WCMC and ReefBase), and terrestrial biodiversity models (Map of Life, GBIF) to inform our broader biogeographical understandings of Swahili human–environment interaction.

Keeping up with the lightning speed of growth in geospatial science is challenging for specialists, and even more so for archaeologists, who have to balance their engagement with other core concerns. But this is to be expected in a maturing field. As archaeologists first and foremost, we might never reach the expertise of a full-time GIS or remote sensing technician. But we do have synthesizing, organizational, and team-building skills that can help us leverage underutilized geospatial data and tool kits toward specific goals.

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Wolfgang Alders *received his PhD in anthropological archaeology from the University of California, Berkeley, in 2022. He was a National Science Foundation SBE Postdoctoral Fellow at the Center for Advanced Spatial Technologies at the University of Arkansas, Fayetteville, from 2022 to 2024 and a visiting research scholar at the Institute for the Study of the Ancient World in 2024–2025. After lecturing at UCLA in fall 2025, he began a postdoctoral position as a Marie Sklodowska-Curie European Fellow at the McDonald Institute for Archaeological Research at Cambridge University. You can find his personal website here: wolfalders.github.io. You can follow the CALOR project at calorarchaeology.com or on Instagram.*

NOTES

1. https://theconversation.com/zanzibars-baobab-trees-used-to-be-a-valued-part-of-society-drone-images-help-prove-it-258996.

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