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Fitton, Tom, Sulas, Federica, Lisowski, Mik et al. (3 more authors) (2022) Integrating spatial and legacy data to understand archaeological sites in their landscape:A case study from Unguja Ukuu, Zanzibar. Archaeological Prospection. ISSN: 1099-0763

https://doi.org/10.1002/arp.1885

Received: 16 February 2022 | Revised: 20 October 2022 | Accepted: 23 October 2022

DOI: 10.1002/arp.1885

RESEARCH ARTICLE

WILEY

Integrating spatial and legacy data to understand archaeological sites in their landscape. A case study from Unguja Ukuu, Zanzibar

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Funding information
This study was funded by a research grant from The Leverhulme Trust as part of the Urban Ecology and Transitions in the Zanzibar Archipelago Project (#RPG-2018-414, 2019–2022), and fieldwork was supported by the Danish National Research Foundation - Centre of Excellence for Urban Network Evolutions (Grant DNRF119), Aarhus University.

Abstract

Spatial analysis is paramount for understanding, monitoring, and conserving ancient settlements and cultural landscapes. Advancing remote sensing and prospection techniques are expanding the methodological frame of archaeological settlement analysis by enabling remote, landscape-scale approaches to mapping and investigation. Whilst particularly effective in arid lands and areas with sparse or open ground cover, such as vegetation and buildings, these approaches remain peripheral in tropical environments because of technical and contextual challenges. In tropical Eastern Africa, for example, scales, resolution and visibility are often compromised by thick vegetation cover, inadequate access to, if not lack of, imagery resources and technologies, and the availability of comparative archaeological data for interpretation. This paper presents the initial results of spatial analysis, using historic landscape characterisation, remote sensing, published and legacy data, and a pilot ground survey to examine the earliest settlement of Zanzibar, Unguja Ukuu. Comparing multiple strands of evidence in a Geographic Information System (GIS), we use each as a test on the others to draw out the strengths and weaknesses of each technique in the context of tropical and coastal Eastern Africa. Drone photogrammetry, geophysical prospection, and ground survey were compared with legacy remote sensing resources and the results of a coring survey conducted across the site during the 1990s into a GIS platform to produce multi-phase hypothetical maps of the archaeological site in the context of its potential resource landscape. These were then tested against the results of recent excavations. The discussion highlights the challenges and potential of combining these techniques in the context of Eastern Africa and provides some suggested methods for doing so. We show that remote sensing techniques give an insight into current landscapes but are less useful in understanding or modelling how sites would have fitted into their surroundings in the past, when conditions were potentially very different.

KEYWORDS
historic landscape characterisation, legacy data, remote sensing, spatial analysis, sub-Saharan Africa, urban ecology

1 | INTRODUCTION

The aim of this paper is to present an evaluative case study of the potential and challenges of using different types of remote sensing imagery and legacy spatial data for archaeological settlement and landscape survey in Eastern Africa, based on the successful identification and confirmation of archaeological features at Unguja Ukuu, Zanzibar. It is part of the Urban Transitions and Ecology on the Zanzibar Archipelago Project (UETZAP), an archaeological investigation which is exploring historic urban ecologies, resource use, and environmental impact related to urbanising settlements on the islands between the 7th–15th centuries.

The site of Unguja Ukuu, on the south-western coast of Unguja Island in the Zanzibar Archipelago, has been the setting for multiple archaeological campaigns aimed at understanding its chronology, nature and external connections (Crowther et al., 2013a, 2013b; Fitton & Wynne-Jones, 2017; Horton & Clark, 1985a; Juma, 2004; Wood, 2016; Wood et al., 2017; Wynne-Jones et al., 2021), whereas palaeoenvironmental studies have explored changing mangrove vegetation as a proxy for sea level rise (Punwong, 2013). As a result, the site is now recognised as one of the earliest trading locations on the east African coast, with demonstrated connections to networks of commodity trade from the seventh century CE. The wealth of data from Unguja Ukuu also makes it an excellent setting for a consideration of a site within its landscape on the eastern African coast.

Two of the key objectives of our project are to investigate resource use in occupation areas and associated middens within the known limits of the archaeological settlement through targeted excavations, and the historic transformation of the surrounding landscape using geomorphological and archaeobotanical analysis.

The time and labour costs of intensive broad area field survey made targeting of suitable areas of the site for investigation a desirable component of the first phase of the project. In order to help with this and to support later analysis of our spatial and temporal data, we constructed a multi-scalar geographic information system (GIS) database to integrate spatial and temporal data from a combination of pedestrian, topographic, remote sensing and near-surface geophysical surveys, as well as primary and legacy excavations. Various sources of high-resolution visible and multispectral satellite and aerial imagery were obtained and used to try to identify archaeological and environmental features relevant to our investigation, which might be targeted for field survey. Although archaeological survey using remote sensing imagery is common in many parts of the world, its use in sub-Saharan Africa remains rare (Khalaf & Insoll, 2019). Our preliminary remote sensing survey demonstrated a number of challenges that contribute to this continuing situation, which are described below. As part of our post-excavation analysis (and given the prevention of ethically appropriate field survey during the COVID-19 pandemic), we experimented with ways of drawing out useful archaeological data and interpretations from remote sensing despite these challenges by adapting the GIS to create a historic landscape characterisation of our survey universe. This enabled cross-referencing of spatial datasets despite issues associated with individual sources, and the results demonstrate the potential of this methodology for integrating primary and legacy data for survey and spatial analysis in Eastern Africa, and for developing interpretations of urban ecologies in the past. This paper describes the initial challenges of remote sensing in Eastern Africa, the methodological process employed to cross-reference these sources, and presents the results of our spatial analysis of the archaeological site at Unguja Ukuu using a combination of legacy data, remote sensing, ground surveys and historic landscape characterisation. We describe the potential of different remote sensing sources for archaeological analysis in East Africa and offer examples of relevant landscape features visible in our survey imagery, as well as a discussion of the anachronistic limitations of remote sensing for digital modelling of past landscapes.

2 | SPATIAL DATA AND REMOTE SENSING IN AFRICAN ARCHAEOLOGY

In recent years, advances in the technologies and datasets available for airborne remote sensing have expanded applications of spatial data for African archaeology. Airborne remote sensing (multi-spectral imagery, Synthetic Aperture Radar [SAR] and Light Detection and Ranging [LiDAR]) alongside survey, near-surface geophysics, and GIS analysis are increasingly used by archaeologists across the continent (Klehm & Gokee, 2020), often in combination with ground-based techniques (Thabeng et al., 2020). Remote sensing for the identification of settlement distribution patterns based on aerial and satellite photos is common in open (vegetation) landscapes, especially in North Africa (Biagetti et al., 2017; Parcak et al., 2017) and southern Africa (Davis & Douglass, 2020; Sadr, 2016; Thabeng et al., 2019). In densely vegetated and canopied tropical environments, techniques capable of penetrating dense canopies, such as LiDAR, have been most transformative. For example, Davis and Douglass (2020) have argued for the potential of automated survey using LiDAR and SAR coupled with machine-learning to identify sites below dense vegetation in Madagascar. By employing tools capable of recording the microtopography beneath foliage in a way that visible photography cannot, this methodology can be used to identify anomalous landforms and features related to human activity, such as house platforms, walls, and sunken or cut features like pits, ditches and quarries. Multispectral datasets are increasingly employed to identify archaeological sites and to build predictive models of site locations based on topographic and environmental contexts (Khalaf &

Insoll, 2019; Reid, 2016, 2020; Thabeng et al., 2020). Several of these have involved the use of high-resolution imagery to flag core settlement areas and related hinterlands based on the environmental impact of cultivation and activity on vegetative health. This ideally requires intensive field sampling of surface, archaeological and agricultural contexts as well as archaeological materials, and subsequent lab-based spectral analysis of samples to build a catalogue of multispectral signatures prior to remote sensing analysis (Gokee & Thiaw, 2020).

Pawlowicz et al. (2020) argue that the potential of remote sensing is only fully realised in combination with a significant quantity of background data to help delimit both remote and ground survey conditions, and on the availability of appropriate and sufficiently high-resolution data. The application of remote sensing for framing systematic ground surveys has been transformative, as seen, for example, in investigations of land use and settlement patterns in the northern Ethiopian highlands (Harrower et al., 2020). Medium and low-resolution imagery has also been used to characterise environmental impact areas related to pastoralist activity (de Mûelenaere et al., 2014; Nyssen et al., 2010; Zerboni et al., 2021), and satellite imagery can also be used as a tool for monitoring sites rather than a primary tool for site detection (Khalaf & Insoll, 2019).

On the east African coast, availability and cost of imagery, dense foliage and vegetation, and variable atmospheric conditions hamper visual survey and remote sensing. Spatial investigations of sites and their associated landscapes in coastal regions have, instead, drawn from shovel test pit (STP) surveys (Fleisher, 2003; Pawlowicz, 2011, 2019). Geophysical survey on coastal sites has also increased since the first applications at Vumba Kuu (Wynne-Jones, 2012), including the exploration of settlements on Zanzibar and Pemba (Fitton, 2017). These spatial approaches were combined at Songo Mnara and Kilwa (Pawlowicz et al., 2021; Welham et al., 2014) together with maritime coastal surveys (Pollard et al., 2012), laser scanning and Global Positioning System (GPS), and area excavations and geochemical sampling across the core urban area (Fleisher et al., 2012; Fleisher & Wynne-Jones, 2012; Wynne-Jones & Fleisher, 2010, 2011; Wynne-Jones & Fleisher, 2014). The level of detail on urban spatial practices that can be examined using this methodology answers a challenge faced by other coastal projects that have focussed on vertical rather than horizontal distribution. In setting out to investigate the urban ecologies of Swahili settlements in the Zanzibar Archipelago, we hoped to refine this method by combining established archaeological ground survey techniques with remote survey for the identification of relevant urban and landscape features to complement our investigation of environmental resource use at such sites.

3 | RESEARCH SETTING AND PREVIOUS SURVEYS OF UNGUJA UKUU

The gazetted archaeological site at Unguja Ukuu on the southwestern coast of Unguja Island preserves the multi-phase remains of the first and principal town of the Zanzibar Archipelago (Figure 1). Today, traces of the site are visible on the surface principally as extensive scatters of Tana Tradition and imported turquoise-glazed ceramic sherds, with glass artefacts and fragments of burned and degraded daub from earthen houses eroding out of road cuts, pits and other modern intrusions into the ground surface. These remains are spread across the landscape among the open beach of Menai Bay to the west, a mangrove creek to the east, and the start of the narrow Ras Makime peninsula to the south. A ruined later medieval structure known as the 'Arab house' (Horton & Clark, 1985a) stands above the beach of Menai Bay, and the expansion of the modern village of Unguja Ukuu Kaepwani has seen the recent construction of three small resorts, a fish market, a mosque and a regional headquarters of the Zanzibar Navy (Figure 2).

The earliest confirmed occupation of the settlement dates to the 7th century CE, with some evidence for earlier activity taking place at the site (Juma, 1996; Wynne-Jones et al., 2021). Between the 7th and 10th centuries, the settlement consisted of clusters of earthen houses, interspersed with craftworking locales. The inhabitants supported themselves with a mixed economy of fishing, farming and hunting, evidenced through the faunal remains found in Unguja Ukuu's rich middens (Crowther et al., 2016; Faulkner et al., 2018; Prendergast et al., 2016). Unguja Ukuu has one of the densest records of imported ceramics found on the eastern African coast during these centuries; it was clearly an early centre of import and export for both objects and foodstuffs (Juma, 2004, 2017; Priestman, 2017; Wilmsen et al., 2018; Wood et al., 2017).

The first systematic archaeological survey of Unguja Ukuu by Horton and Clark (1985a) mapped surface sherds and midden deposits to estimate the total size of the site and included the excavation of three test pits to date the occupation sequence. Between 1989 and 1994, Abdulrahman Juma, an author of this paper, conducted a series of magnetometry and resistivity surveys, an extensive programme of coring, and targeted excavations (Juma, 2004). The survey identified a number of coral structures presumed to represent houses, several burials across the site, and buried remains of a 9th century coral mosque on a promontory above the mangrove creek at the eastern edge of the site. This investigation also represented the first (and until recently the only) project to survey the wider region around Unguja Ukuu and to attempt to understand the archaeological site within its contemporary landscape.

In recent years, palaeoenvironmental research in the creek to the east of the site has provided a long-term record of sea-level change through the proxy of changes in mangrove species (Punwong et al., 2013), whereas further test pit excavations by the Sealinks Project focussed on midden deposits and trade artefacts (Boivin et al., 2014; Crowther et al., 2015; Faulkner et al., 2018). Subsequently, a magnetometry survey, limited excavations, and investigations of the harbour areas were conducted by two authors of this paper funded by the Entrepôt Project (Fitton, 2017; Fitton & Wynne-Jones, 2017). Since 2017, we have been developing new area excavations and surveys in and around the site as part of UETZAP (Sulas et al., 2019; Wynne-Jones et al., 2021).

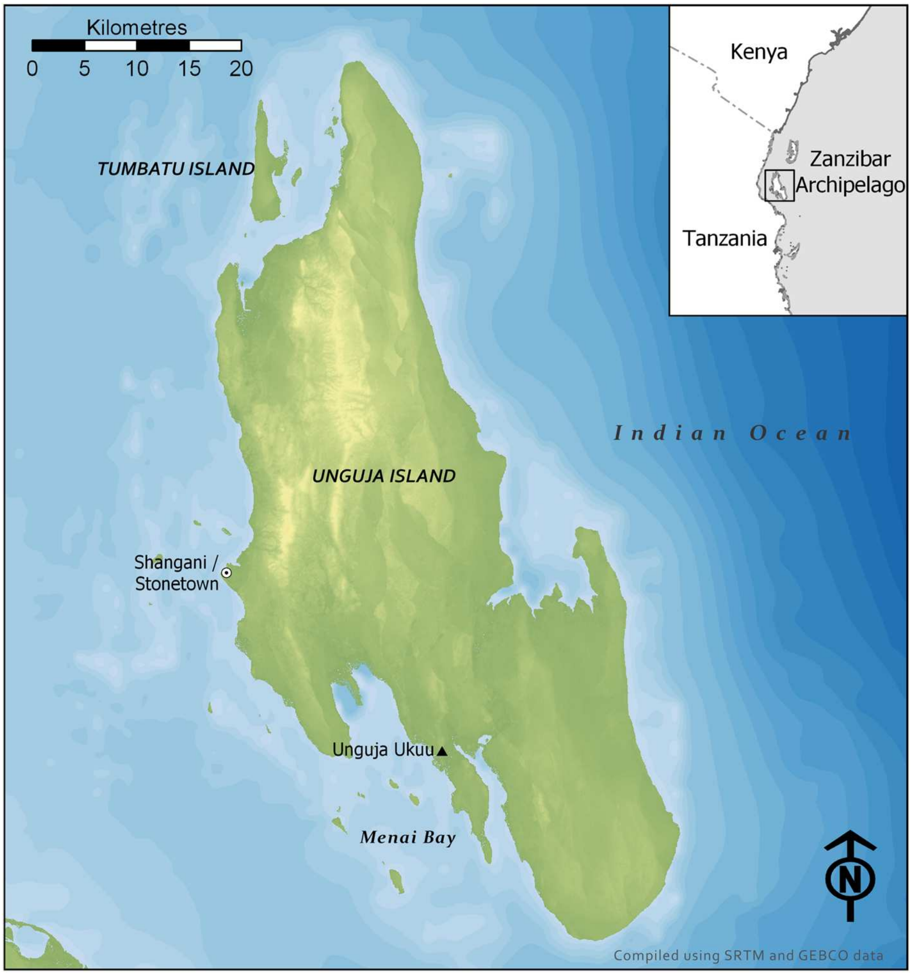


FIGURE 1 Location map of Unguja Ukuu, Zanzibar [Colour figure can be viewed at wileyonlinelibrary.com]

The range of surveys and excavations conducted at Unguja Ukuu over the past 35 years therefore provide a broad dataset for aspects of the site's chronology and occupation. Information from multiple test pits and sampling programmes carried out with different aims is however difficult to resolve into a spatial understanding of the settlement layout and its placement in the landscape.

4 | ADAPTING HISTORIC LANDSCAPE CHARACTERISATION FOR SURVEY AT UNGUJA UKUU

As noted above, remote sensing has proven to be an excellent technique for mapping archaeological features and spatial distributions under suitable geographic and environmental conditions, but its use in sub-Saharan Africa at large, and especially in eastern Africa, remains relatively rare, and most scholars advocate the combination of remote sensing data with ground-based techniques. This assumption guided our approach to the site of Unguja Ukuu. As we set out to understand the spatial layout of the site in its landscape, issues with available datasets, environmental factors and unrecorded developments related to the modern use of the area made it clear that an integrated approach to survey methodologies would yield the best results.

Historic landscape characterisation (HLC) is an emergent conceptual and practical framework for understanding 'historic' landscapes as ubiquitous and continuous, that is as places that are perceived and the result of variation across time (Turner, 2006, 2018). First developed in England, historic map regression and HLC have proven useful tools for understanding the nature of the modern landscape and potential impact of recent change on buried archaeological features in Europe. In practical terms, historic map regression involves the plotting of landscape features from a sequence of historic maps and adjacent survey datasets to build a periodised GIS of landscape change over time through the superimposition of datable features and relative terminus ante quem changes. The relative paucity of historic maps of Zanzibar means, however, that the results of our map regression exercise were limited and not particularly useful.

HLC by comparison uses plotting of multi-scalar and multi-period landscape features from a variety of sources with the aim of building a GIS from which it is possible to identify the predominant historic character of a given area of land and the patterns of development which have shaped the creation of the modern landscape. Although historic map regression requires a sequence of suitably detailed and accurate historic sources related to the survey area to map the progressive change of landscape features, HLC benefits from such evidence of chronological developments but does not require it. This

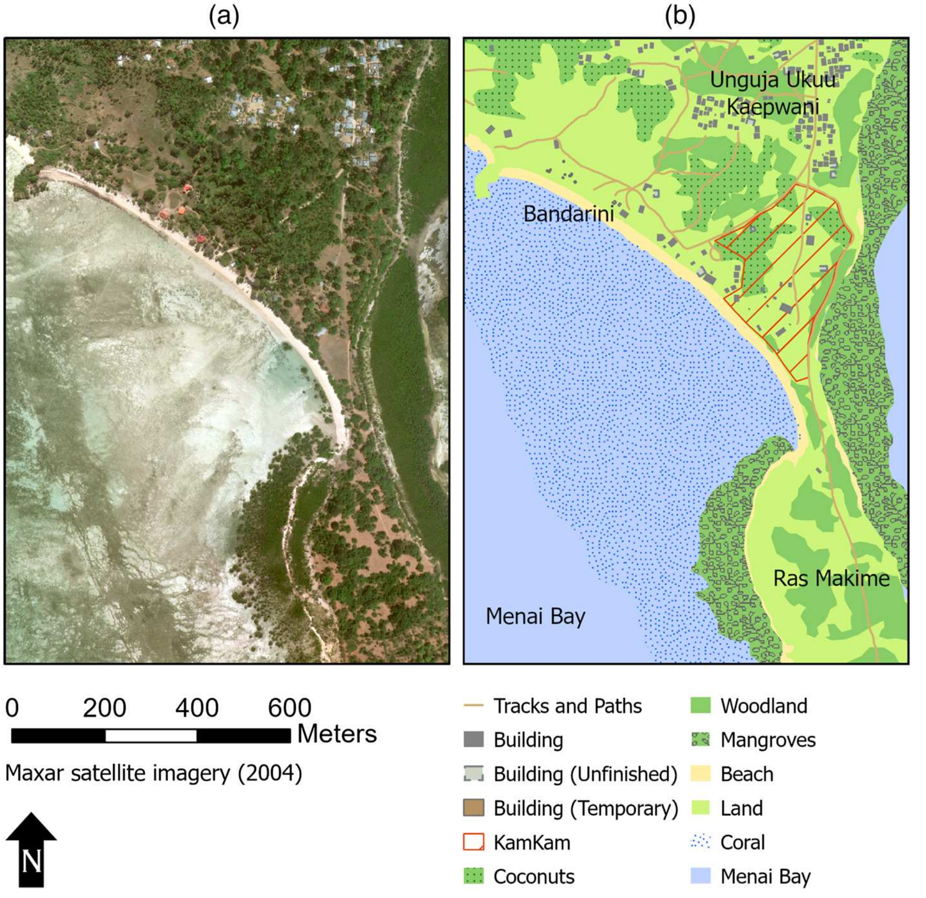


FIGURE 2 (a) MAXAR satellite imagery (2004) of Unguja Ukuu and (b) modern landscape characterisation of the same landscape derived from satellite and drone imagery [Colour figure can be viewed at wileyonlinelibrary.com]

aspect of HLC is a significant advantage in our survey area given the lack of historic sources. A second major advantage of HLC is the opportunity for inclusion of community and public perceptions of place as significant aspects of the landscape, enabling us to integrate data from local community informants, survey assistants and a participatory GIS survey in Unguja Ukuu Kaepwani carried out in collaboration with the State University of Zanzibar (Fitton et al. forthcoming). We have therefore been able to create a GIS that contains spatial archaeological data with specific temporal contexts, spatial data without temporal contexts and landscape features which may be relevant to one or more phase of occupation but which may not require temporal resolution. In this way, although HLC was originally developed for use in a context with a greater quantity of historic data, adopting the principles of HLC mapping for our investigation of Unguja Ukuu offers the opportunity to more effectively explore the landscape context of the site and set up hypothetical models of settlement layout and palaeolandscapes for testing.

4.1 | Project GIS methodology

We have adopted the principles of HLC and adapted our GIS to map the probable spatial extent of the settlement in a given temporal frame, as well as the proximity to the settlement of period-relevant environmental resources. The GIS contains spatial datasets representing archaeological remains mapped from legacy publications and our own fieldwork and remote surveys, and complementary datasets including topographic models, geological features and environmental indicators as a means of contextualising the archaeological settlement in a hypothetical model of the contemporary palaeolandscape. Relevant landscape features identified in our GIS datasets were plotted and flagged as archaeological, modern or environmental polygons. Attribute fields were added so that features can be assigned temporal attributes related to a specific century or period (usually a range of centuries for archaeological materials/contexts without absolute dates), or as essentially permanent features in the case of certain environmental resources (for example, coral outcrops). This means that the possible extent of the settlement in each period can be estimated based on the presence of potential archaeological indicators, and probable extent based on overlapping indicators from more than one source and/or confirmed evidence of archaeological occupation or activity. The method also enables us to compare the presence and proximity of archaeological materials in a given area of the site to the nearest available source of such materials. Small coral inclusions in an auger core, for example, may not be significant if there is a known coral outcrop in the vicinity, but the identification of coral rubble on the surface may be significant in an area otherwise composed of sand or silt with no known coral outcrops. Known modern landscape features such as structures, wells, plantations, field systems and secondary woodland can also be flagged as potential disturbances or anachronisms. In this way, we have tried to enable 'fuzzy' cross-referencing of limited or low-resolution archaeological datasets whilst building in reminders of the temporality of landscape features that might otherwise be presumed longue duree.

4.2 | Integrating datasets

Although we drew mainly on our own fieldwork, we have also used a range of archaeological, environmental and topographic data from published sources into the GIS. Several factors complicate this process, including the different purposes for which data have previously been gathered (archaeological, geographic, ecological and cartographic); the means and styles of publication (descriptive texts, charts, tables and maps); and spatial and temporal resolutions of data (including scale of surveys, relative coordinate systems and periodisation). This means that although spatial datasets may appear visually to be combined and directly comparable in GIS, some datasets are not combined but overlaid, a process that can obfuscate significant variation between sampling methods and resolutions. Differences between the original spatial and temporal data resolution necessitate a degree of uncertainty be taken into account during analysis and interpretation. Our adaptation of the principles of HLC has enabled us to integrate different sources in the GIS for cross-referencing whilst allowing for necessary 'fuzzy' data differences and resolution, and we have tried to be open about such fuzziness in this paper.

The range of studies and publication formats across the past 35 years also means that incorporating legacy results into the GIS, and our analysis has involved a sometimes complicated process of reconciling and rectifying different types of data and formats. This includes the digitisation and georectification of archaeological maps; digitisation and plotting of data originally published as tables, charts and literary descriptions; and the collation of a range of topographic, geological and hydrographic data from a range of paper and digital archives, some of which were originally compiled by Fitton (2017). This process has therefore involved the identification and correction of potential issues, including positioning errors on paper maps, inaccurately rectified digital datasets, and unknown coordinate systems (especially predating the declassification of GPS in 1983 and cancellation of a signal downgrading programme known as 'selective availability' in 2000 (GPS.gov, 2021). These have been dealt with as best as can be managed under the circumstances, and where possible in discussion with the original authors. The issues are discussed here not as a criticism of the original publications but as a demonstration of both the challenges and benefits of working with legacy data.

Once these issues had been resolved, archaeological, historic and environmental indicators were then mapped as polygon shapefiles in a multi-scalar GIS alongside the topographic, ecological and remote-sensing datasets. This enabled us to explore historic landscape characteristics as areas of potential archaeological interest in the palaeo-landscape, as well as to identify probable taphonomic disturbances of the archaeological record related to modern occupation of the area. The results of analysis so far are encouraging both in the generation of relevant data for our own project, and as a model for integrating remote sensing based and field data in Eastern Africa. Here we describe the methods used for each of these datasets, together with an evaluation of their utility in understanding the landscape surrounding Unguja Ukuu in the first millennium CE.

4.3 | Legacy data

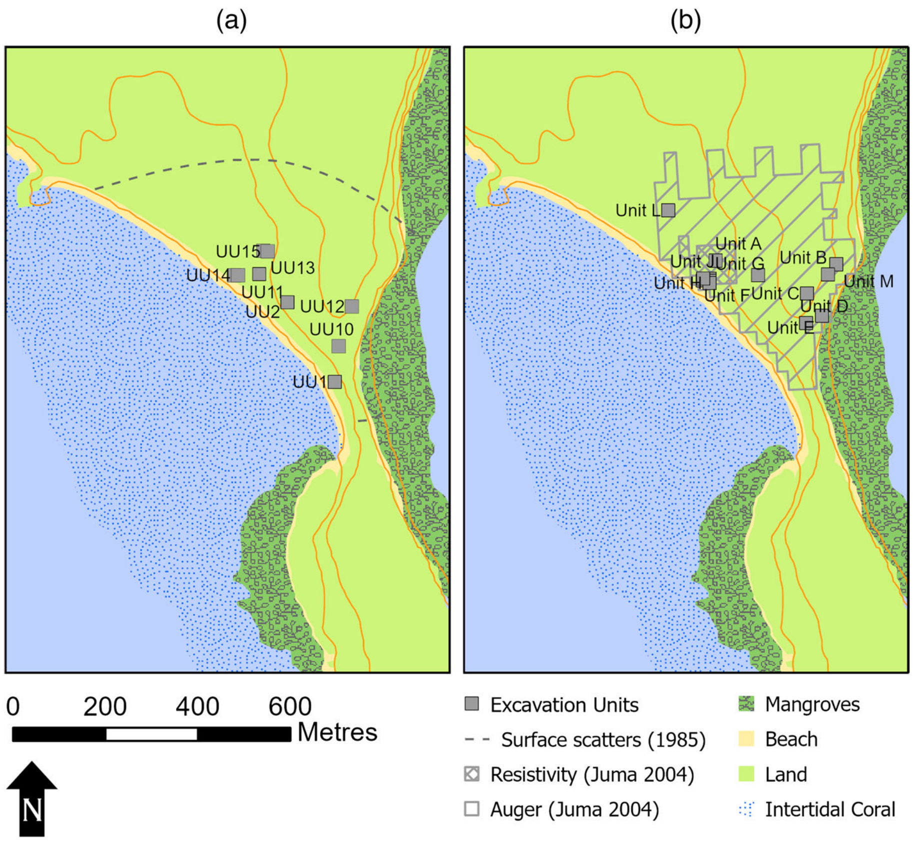
4.3.1 | Early surveys

Data from the previous survey and excavations conducted by one of the authors (Juma, 2004) and by Horton and Clark (1985a) were integrated into our GIS. Horton and Clark's (1985a) survey of Unguja Ukuu produced the first estimation of the total size of the archaeological settlement based on surface scatters of ceramics and estimated dates of the main occupation sequence based on three 1-m wide test pit excavations. The resulting sketch map of the archaeological site was published in a gazetteer, and incorporation into our own GIS (Figure 3a) required digitisation and careful georectification to account for inconsistencies between the coastline of the sketch map and satellite imagery, which formed the base of our GIS. Discussion with Horton (2016 personal communication) revealed that broken sightlines across rising ground and through tree cover prevented the accurate survey of the wider landscape at the time, and the sketch map was therefore georectified to fit the permanent features of the landscape, coastline, and prominent features that Horton noted were clearly visible from their main survey area at the time.

Investigations in the 1990s as part of the Urban Origins Project included a wider landscape survey, coring, geophysical resistivity and magnetic surveys, and test pit and excavation trenches (Juma, 2004); Figure 3b). The coring survey produced what was in essence a heat map of the thickest cultural deposits across the site, whereas the geophysical resistivity survey was used to try to identify the buried remains of structural features. Together, these surveys were then used to excavate trenches in probable occupation areas, which subsequently revealed a mix of daub structures with associated artefacts, burials and the remains of at least one probable coral-rag mosque dating to the 9th century. This succeeded in producing a much-improved model of the site's occupation sequence, fluctuating population levels, and trading fortunes between the 6th and 15th centuries.

Mapping of these surveys and excavations in the 1990s was based on a site grid tied to a benchmark survey point ('ZAN64') placed by the Zanzibar Department of Land and Surveys, which appears to have subsequently been buried or destroyed by construction in the grounds of the regional headquarters of the Zanzibar Navy (Makao Makuu ya Kamandi ya Kusini, generally referred to locally as 'Kam-Kam'). Georectification of the survey plans from this fieldwork as complementary data for UETZAP indicates, however, that although the maps are detailed, accurate and internally consistent, the original projected coordinates of the ZAN64 benchmark may have been miscalculated. Re-rectification to landforms and surviving architectural features demonstrates a consistent 300 m and 3° discrepancy

FIGURE 3 (a) Surveyed site extent and excavation units UU1-3 from Horton and Clark (1985) and UU4-15 following same numbering scheme by Crowther et al. (2013a), and (b) excavation units and site survey areas by Juma (2004) [Colour figure can be viewed at wileyonlinelibrary.com]



between the ZAN64-derived coordinates and our more recent GPS-based survey data collected since 2013 (Figure 4). This process illustrates the problems caused by rapid development of both urban areas and technology, as well as the value of establishing a semi-permanent site grid with multiple landmarks, as Juma (2004) did, to enable re-rectification of location data against independent sources.

Solving the issue of reprojection also opened the door for us to utilise supplemental data from the original surveys that were published not as maps but in alternative formats. This supplemental data included a complete set of graphic charts recording the coordinates and relative elevations of every core sample taken; measurements of phosphate levels; and brief descriptions of the depth, colour and texture of the stratigraphy; as well as notes on inclusions encountered in every stratigraphic unit (Figure 5a). We digitised these charts as an excel database (Figure 5b) and have used this resource to plot both horizontal distribution maps and vertical cross-sections of recorded inclusions across the site (Figure 6).

4.3.2 | Modern test excavations and geophysics

The Sealinks Project excavated several test pits in midden contexts previously mapped by Horton and Clark (1985b), continuing an excavation numbering scheme started in 1984 (Crowther et al., 2013a, 2013b) (Figure 3a). These units recovered various trade artefacts that helped establish long-distance trade links across the Indian Ocean and zooarchaeological materials that were used to develop our understanding of changing patterns of probable wild/domesticated faunal exploitation over time. The locations of these trenches were plotted in our GIS from unpublished site reports submitted to the Department of Museums and Antiquities of Zanzibar, along with metadata related to archaeological contexts and materials. This was then used for targeting our own excavations towards occupation-adjacent middens in 2019 and for comparison of excavated occupation sequences.

The results of the magnetic gradiometry survey carried out in 2013 by the Entrepôt Project (Fitton & Wynne-Jones, 2017) have been included in the GIS as a means of aiding positioning of UETZAP excavation trenches and contextualising our work within the known urban landscape (Figure 4a). This survey was conducted with the aim of investigating the spatial layout of the site and identified a previously unknown circa 9th century-coral-and-daub mosque on the south-western shoreline (Figure 4a, Trench UUB1). A possible harbour-related crafting and trade activity area was also hypothesised (Fitton, 2017) in the vicinity of the parade ground on the basis of thermoremanent magnetic anomalies and unusual frequency of metal remains in midden deposits identified by a complementary metal-detecting survey.

The UETZA Project has so far conducted two seasons of fieldwork at Unguja Ukuu (Figure 4b). In 2017, a daub structure and associated external spaces were excavated and sampled for systematic geochemical mapping. Careful single-context excavation revealed two distinct levels of occupation, marked by packed earth floors and associated crafting activity area outside the former wall. Microstratigraphic

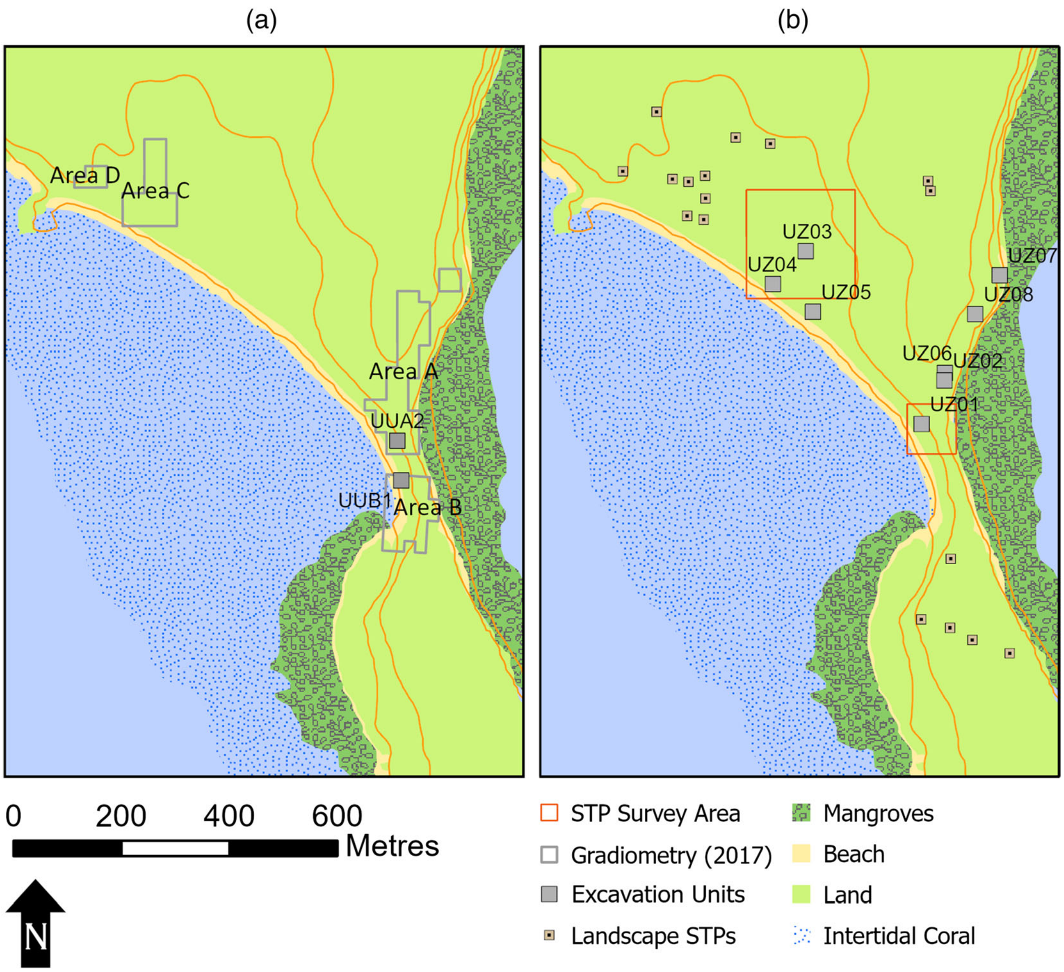
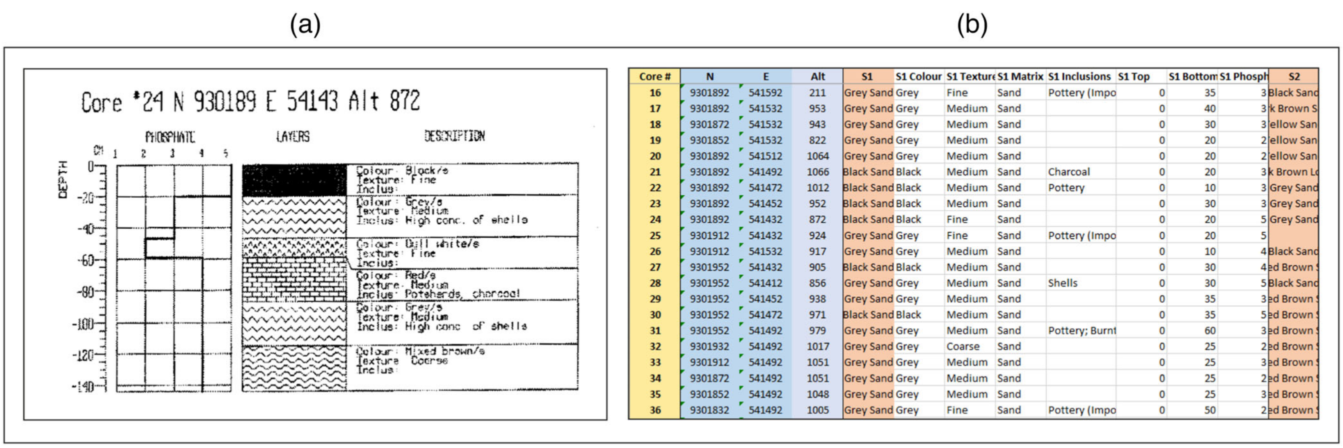


FIGURE 4 (a) Survey and excavation areas by Fitton and Wynne-Jones (2017), and (b) excavation and survey areas investigated as part of the UETZA project. UETZA, Urban Transitions and Ecology on the Zanzibar Archipelago Project [Colour figure can be viewed at wileyonlinelibrary.com]



Core #	N	E	Alt	S1	S1 Colour	S1 Texture	S1 Matrix	S1 Inclusions	S1 Top	S1 Bottom	S1 Phosph	S2
16	9301892	541592	211	Grey Sand	Grey	Fine	Sand	Pottery (Impo	0	35	3	Black Sand
17	9301892	541532	953	Grey Sand	Grey	Medium	Sand		0	40	3	k Brown S
18	9301872	541532	943	Grey Sand	Grey	Medium	Sand		0	30	3	ellow San
19	9301852	541532	822	Grey Sand	Grey	Medium	Sand		0	20	2	ellow San
20	9301892	541512	1064	Grey Sand	Grey	Medium	Sand		0	20	2	ellow San
21	9301892	541492	1066	Black Sand	Black	Medium	Sand	Charcoal	0	20	3	k Brown Lo
22	9301892	541472	1012	Black Sand	Black	Medium	Sand	Pottery	0	10	3	Grey Sand
23	9301892	541452	952	Black Sand	Black	Medium	Sand		0	30	3	Grey Sand
24	9301892	541432	872	Black Sand	Black	Fine	Sand		0	20	5	Grey Sand
25	9301912	541432	924	Grey Sand	Grey	Fine	Sand	Pottery (Impo	0	20	5	
26	9301912	541532	917	Grey Sand	Grey	Medium	Sand		0	10	4	Black Sand
27	9301952	541432	905	Black Sand	Black	Medium	Sand		0	30	4	ed Brown S
28	9301952	541412	856	Grey Sand	Grey	Medium	Sand	Shells	0	30	5	Black Sand
29	9301952	541452	938	Grey Sand	Grey	Medium	Sand		0	35	3	ed Brown S
30	9301952	541472	971	Black Sand	Black	Medium	Sand		0	35	5	ed Brown S
31	9301952	541492	979	Grey Sand	Grey	Medium	Sand	Pottery; Burnt	0	60	3	ed Brown S
32	9301932	541492	1017	Grey Sand	Grey	Coarse	Sand		0	25	2	ed Brown S
33	9301912	541492	1051	Grey Sand	Grey	Medium	Sand		0	25	3	ed Brown S
34	9301872	541492	1051	Grey Sand	Grey	Medium	Sand		0	25	2	ed Brown S
35	9301852	541492	1048	Grey Sand	Grey	Medium	Sand		0	25	3	ed Brown S
36	9301832	541492	1005	Grey Sand	Grey	Fine	Sand	Pottery (Impo	0	50	2	ed Brown S

FIGURE 5 (a) Example of auger core archive from Juma's (2004) survey of Unguja Ukuu and (b) redigitised version of the same dataset as spreadsheet [Colour figure can be viewed at wileyonlinelibrary.com]

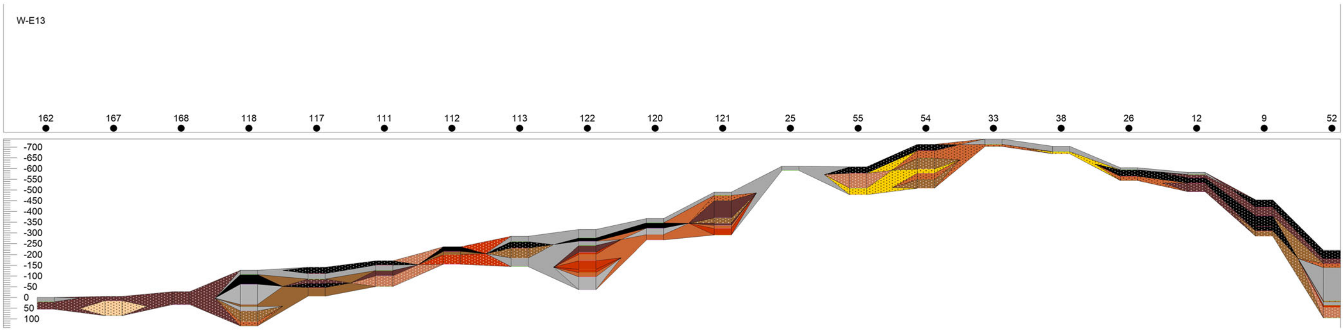


FIGURE 6 Example stratigraphic cross-section of site derived from Juma's auger survey and compiled in Strater 5 geological modelling software [Colour figure can be viewed at wileyonlinelibrary.com]

analysis and high-definition radiocarbon dating of a sequence of samples from floor surfaces also demonstrated that the two occupation phases occurred within approximately 35 years each within the same structural footprint (Wynne-Jones et al., 2021). Excavation plans and geochemical heat maps from these excavations were overlaid within the GIS and revealed the spatial correlation between iron-working debris outside the walls of the structure recorded during excavation, with a ferrous magnetic anomaly recorded in the gradiometry survey area.

In 2019, an expanded programme of open trenches targeted areas of daub house remains and associated middens, and a broad STP survey of the surrounding landscape to investigate potential evidence of agriculture, management and ecological impact during the occupation of the settlement. Drone-mapping was employed to construct a high-resolution Digital Terrain Model (DTM) of the modern landscape to compare to a previous model surveyed by Juma (2004), both to locate elements of the site within the topographic landscape and to identify areas of significant erosion, destruction, progradation, and other recent landscape changes and urban expansion. This has enabled us, for example, to compare the interpolated north–south profiles of the landscape before and after the bulldozing of the Kam-Kam parade ground and to calculate an estimated depth of sediments lost or disturbed as a result (ranging between 40 and 120 cm) (Figure 7). The combination of this process, our on-site STP survey, and a comparison of our excavation profiles against geological cross-sections interpolated from the earlier coring data have also enabled us to state with some confidence that the buried stratigraphy beyond a 10–15 cm disturbed horizon below the current surface of the parade ground appears to represent secure and undisturbed contexts, rather than spoil disturbed by bulldozing.

5 | THE LAYOUT OF THE SETTLEMENT

Our adaptation of the principles of HLC and subsequent analysis of the GIS show patterns in the spatial and temporal distribution of artefacts across the archaeological site at Unguja Ukuu, which suggests a necessary reinterpretation of the first millennium settlement plan. Our reanalysis of auger survey data, in particular, indicates potential spatial correlations between different types of artefacts that might reflect activities taking place in specific loci. For example, although the presence of stone or coral alone at a given sample point might be natural, we have taken the presence of both stone/coral *and* daub or mortar as a potential indicator of architectural remains. Because core samples were taken in the key area of the site at 20 m intervals, a cluster of such find-spots (calculated in ArcGIS based on three or more correlations within 40 m of each other) may then indicate an occupation area rather than a single structure. Caveats to this method are gaps in the survey data where core spacing was increased away from the perceived central locus of the site, and that the original record of inclusions records a qualitative presence/absence but does not include quantified data that might be used to calculate relative artefact densities across the site.

5.1 | Presence and absence

Plotting the spatial distribution of artefacts demonstrates, for example, that subsurface pottery sherds were recorded across the extent of the site but not in every core, and that the general spread roughly correlated with the site extent based on surface scatters reported by Horton and Clark (1985a) (Figure 8). Analysis and comparison of *all* inclusions further show that although archaeological remains are found spread across the wide survey area of the site, a number of cores featured no artefact inclusions at all. Although individual or even pairs of cores with no recorded artefacts may be the result of chance or statistical anomaly, clusters of three or more would seem to indicate areas within the site with little or no evidence of archaeological structures or occupation (Figure 8a). Such clusters of cores with no recorded inclusions may represent either ‘gaps’ in the settlement landscape between concentrations of artefacts or areas of intangible archaeological activity. Clusters without inclusions in the northern area of the survey are not considered reliable indicators of absence, because this area was surveyed at a lower resolution than the core of the site, with samples in line still at 20 m but transect spacing of 100 m. Gaps in the denser central and southern area with 20-m core resolution are more worthy of note; in particular a region with no recorded artefact inclusions is noted running SW–NE between the

FIGURE 7 (a) MAXAR satellite image (2004) of Unguja Ukuu showing Kam-Kam and bulldozed area of parade ground, and (b) comparative elevation profiles of area of parade ground before and after bulldozing derived from Juma (2004) and UETZAP GPS surveys. UETZA, Urban Transitions and Ecology on the Zanzibar Archipelago Project; GPS, Global Positioning System. [Colour figure can be viewed at wileyonlinelibrary.com]

beach and up onto the ridgeline in the middle of the site. This area, which on average is around 40-m wide, does not correlate with any geological or topographic features that might prevent occupation or preservation of archaeological remains, or with roads or areas of recent occupation that might have destroyed or disturbed contexts and materials. We hypothesise instead that this may represent either a gap between concentrations of occupation in the central area of Menai beach and along the edge of the mangroves, or an area reserved for other potentially intangible purposes, and we are currently exploring hypothetical explanations and motivations for such a pattern.

5.2 | Middens

Shell middens are found across the survey area, and inclusions of shells and particular concentrations of shell deposits were recorded in auger cores in a number of locations in Juma (2004). These concentrations appear to map as larger clusters in several areas of the site and were noted as possible middens. A particularly large cluster is visible in the central area of the site (Figure 8b), and a small cluster of high concentration is visible on the eastern edge of the site in the area of (Juma, 2004) Unit M. A third cluster is noted in the northwestern area of the survey, but given the gap between survey transects in this area,

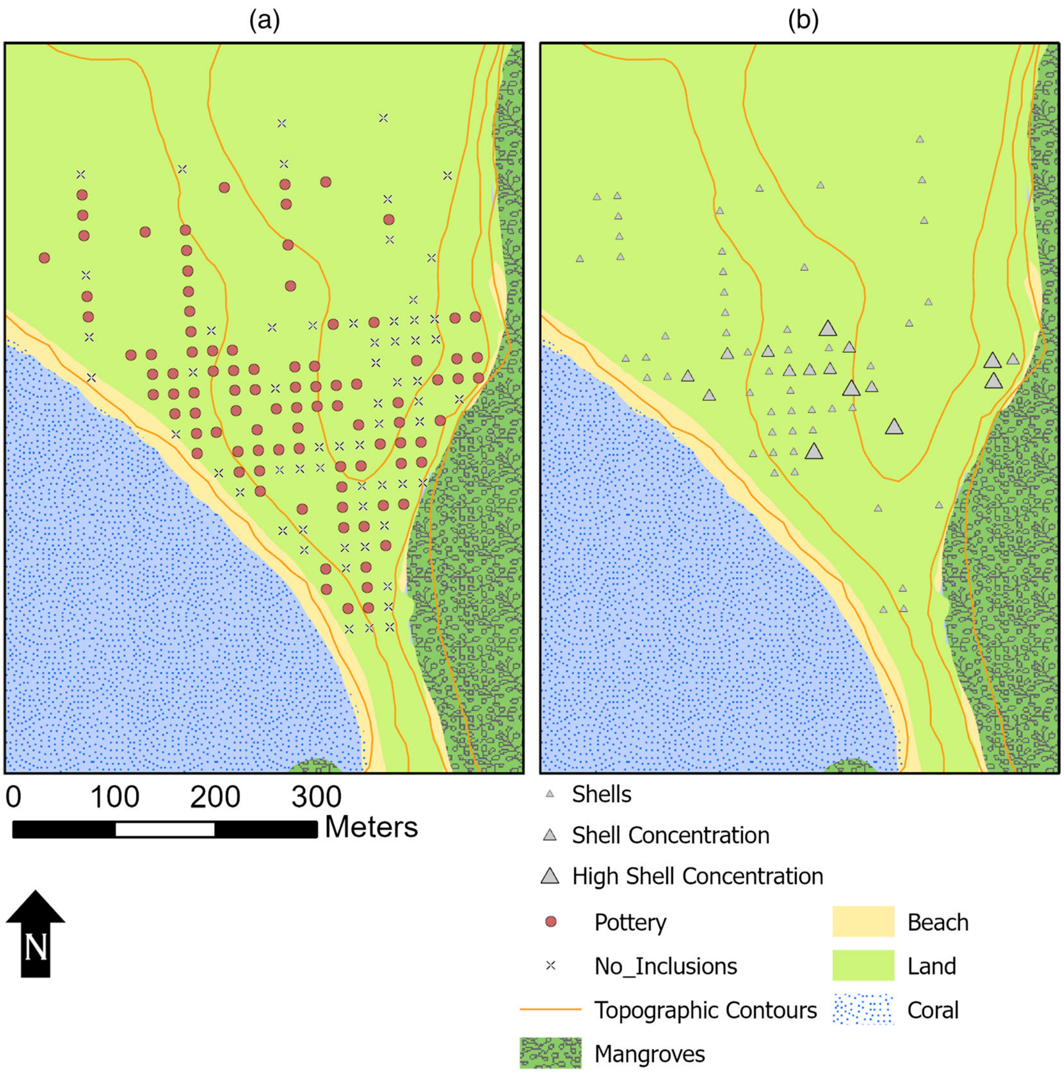


FIGURE 8 Distribution maps of (a) pottery inclusions and absences of archaeological evidence and (b) shell inclusions recorded in Juma's (2004) auger survey [Colour figure can be viewed at wileyonlinelibrary.com]

it is possible that this represents a continuation of the central cluster rather than a separate entity. Shell clusters largely correlate with plots of architectural inclusions. It is also interesting to note a possible correlation between clusters of architectural material, particularly of daub, clusters of shell, and the locations of middens seen on the surface of the site (Horton & Clark, 1985b). Middens seem to have been located in close proximity to occupation and living areas.

5.3 | Architectural remains

Artefact inclusions in the cores were classed together as representative remains of certain types of activity, and spatial correlations between these artefacts were noted as reliable indicators of a locus of that activity. Inclusions of daub, coral, stone, mortar and plaster were classed as architectural materials. Analysis of spatial correlations within this class indicates distinct clusters of architectural materials across the survey area (Figure 9).

Coral is a common geological feature on Zanzibar, because the island itself has a coral bedrock, and chips and blocks known as coral rag are known to have been used as an inclusion in daub walls on the Swahili coast from around the 8th century CE, and as a primary building and carved decorative material in urban settlements from the 10th century (Gensheimer, 2017). Coral was noted, however, in just six locations in the coring survey, although limestone, sandstone and ‘stones’ were recorded in 87 cores (Figure 9a). Given the known presence of coral structures in several parts of this site, it is possible that other examples exist but were too small to be positively identified. Four of the six incidences of coral are located along the line of the beach in the central area of the site, in an area which was subsequently excavated by Juma (2004). At least one of these records of coral in the cores is probably related to the remains of the ‘Arab house’, an 18th-century Omani structure (Horton & Clark, 1985a).

The discovery of dressed porites coral fragments in Unit J and related deposit of white sand suggests that these may represent the remains of a mosque (Juma, 2004). The integration of the auger data

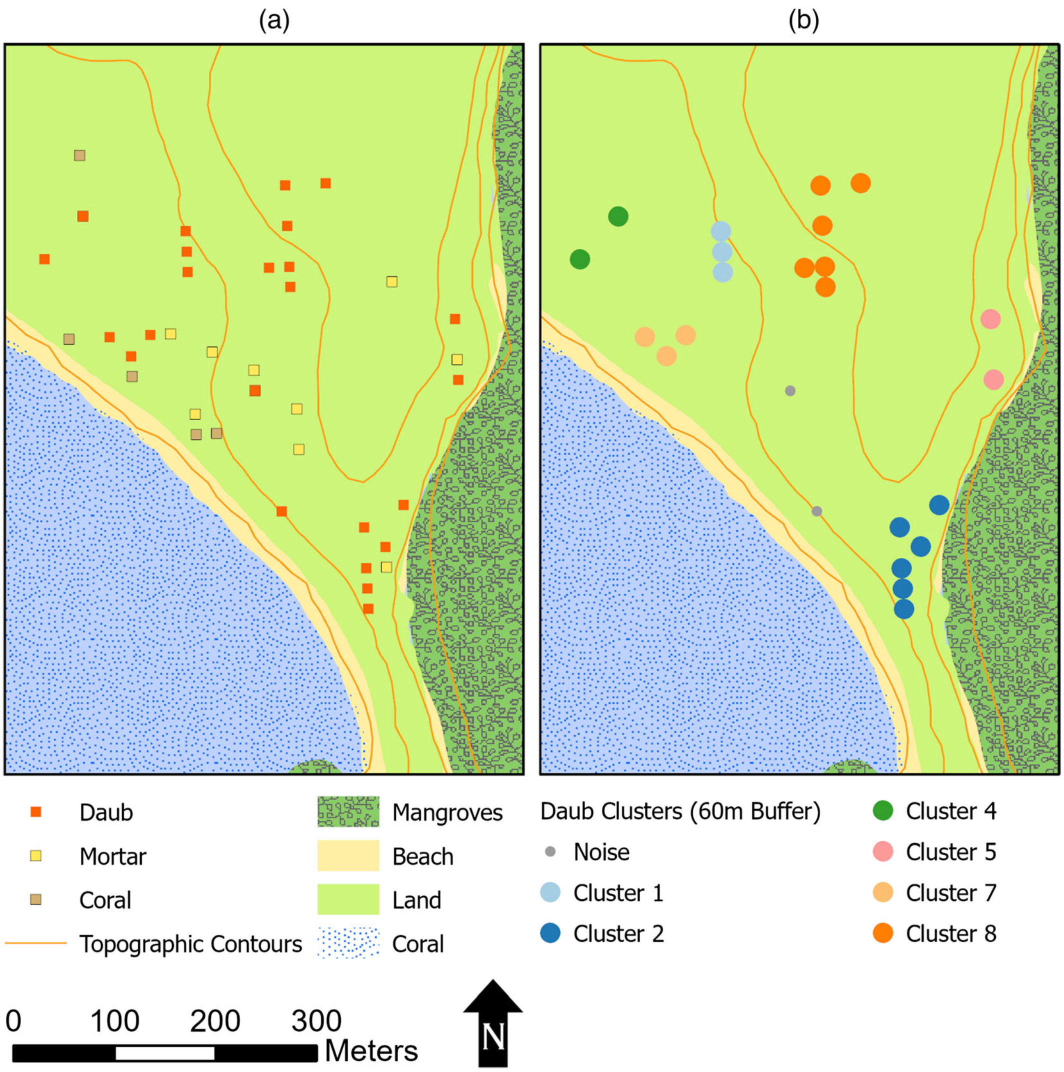


FIGURE 9 Distribution maps of (a) daub, mortar and coral inclusions representative of architectural materials and (b) cluster analysis of daub inclusions recorded in Juma's (2004) auger survey [Colour figure can be viewed at wileyonlinelibrary.com]

into our GIS alongside a resistivity survey also carried out in the 1990s demonstrates a neat correlation between coral and daub inclusions in core samples with a rectangular and high-resistance anomaly approximately 10 m in length just above the beach (Figure 10). However, the rectification of modern satellite imagery also shows that this area and the location of these trenches were subsequently either buried or destroyed by the construction of a resort on the shoreline of Menai Bay. An unusually large number of coral rag pieces are visible today within the grounds of this area, but a test geophysical survey grid confirmed that resort structures, shallow buried water pipes, and electricity cables means that systematic magnetic gradiometry is no longer reliable, and other surface obstacles and disturbance now prevent either resistivity or reliable contact for ground-penetrating radar.

Daub inclusions were not recorded as a common inclusion in cores but seem to map in fairly discrete clusters across the site (Figure 9a). Six clusters of daub were identified using the spatial analysis toolset of ArcGIS, although given the gaps in survey transects, four of these in the northwestern part of the survey area could belong to one large group extending SW–NE from the beach (Figure 9b). This analysis was supported by the results of our survey, which recorded daub both in STPs, and eroding out of buried contexts onto the surface. Correlations of incidence and absence with other inclusions in the eastern part of the site suggest that the two clusters of daub on the shores of the mangrove area may represent distinct groupings. Indeed, our excavations indicate an early occupation area close to the 'neck' of the peninsula (Wynne-Jones et al., 2021) and a later occupation to the north in the vicinity of the coral mosque. Mortar was noted in a number of cores in an area behind the beachfront, although curiously not generally alongside either daub or coral.

6 | THE SITE IN ITS LANDSCAPE

Fitton's (2017) previous investigation emphasised the likely importance of the coastal landscape to the early settlers of Unguja Ukuu, and the apparently deliberate choice (indicated by a pattern identified

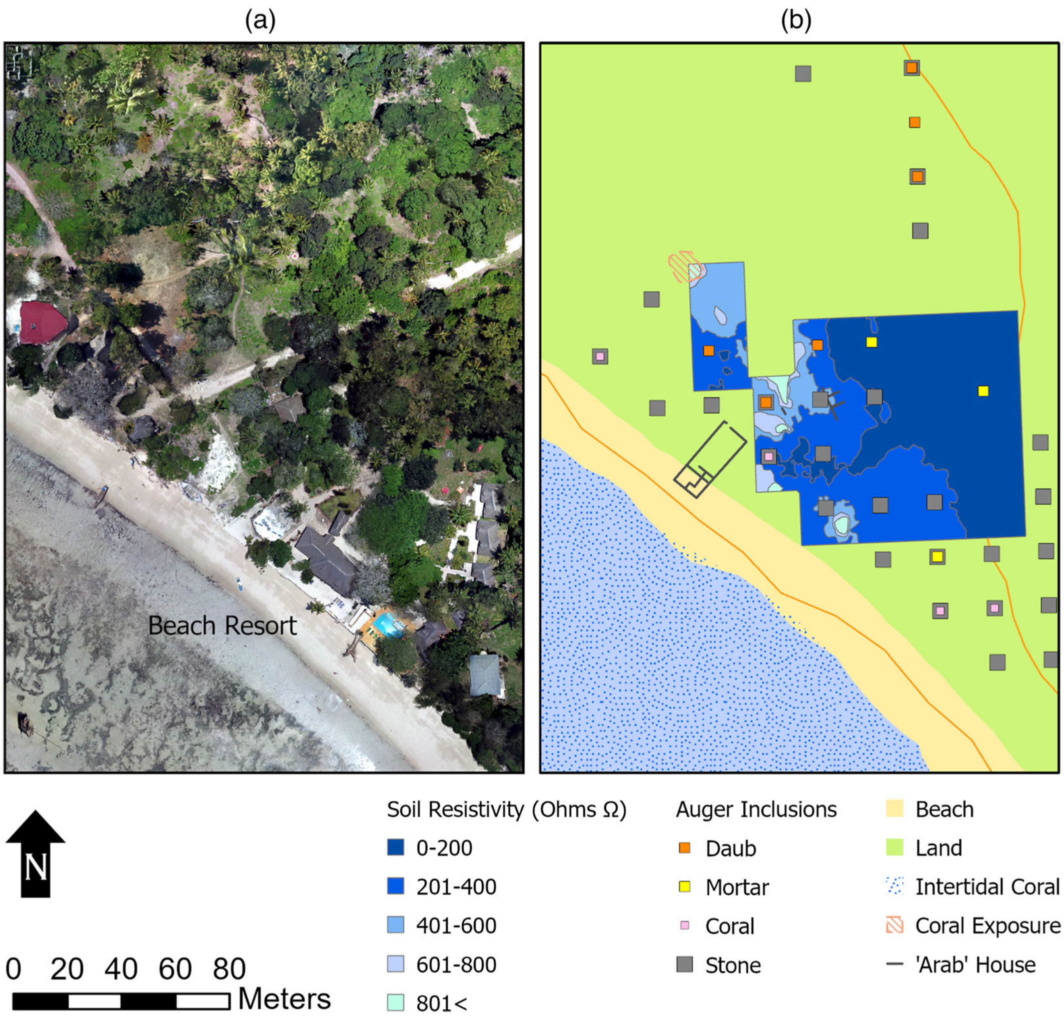


FIGURE 10 Comparative images of (a) UETZAP drone photogrammetry survey of Unguja Ukuu beachfront and (b) integrated results of Juma's (2004) auger survey, electrical resistivity survey and UETZAP landscape characterisation from drone imagery. Note the correlations of daub in core inclusions and coral exposure mapped from drone photogrammetry with high-resistance anomalies. UETZA, Urban Transitions and Ecology on the Zanzibar Archipelago Project [Colour figure can be viewed at wileyonlinelibrary.com]

across the archipelago) of establishing a coastal location with a sheltered beach for landing, and an intertidal zone and adjacent mangrove creek for marine resources and subsistence. UETZAP is performing a resource mapping across the site and landscape using remote survey of satellite and drone imagery, and ground survey.

The challenge for archaeological analysis remains, however, the separation of anachronistic modern features and landforms from those elements relevant to the past occupation of the palaeolandscape. Recent changes in the landscape of the site include, for example, clearance of woodland and ground for farms and plantations; erosion of the beach caused by sand-quarrying in the 1990s (Nyandwi, 2001) and perhaps to recent reshaping of the beach profile related to construction observed in 2019; bulldozing and clearance of an area of the archaeological site to construct the parade ground and to carve a new road around the edge of the Kam-Kam in the 1990s (Horton 2016, personal communication); and the construction of a significant number of new buildings and expansion of the fish market at Unguja Ukuu Kaepwani.

Some of these changes are large or distinct enough to be potentially visible in satellite imagery pre- and post-dating the relevant event. As well as mapping resources in the local environment, we have therefore also attempted to identify recent landscape change events in historic maps and satellite imagery in an attempt to filter out modern features, and to understand potential disturbances and losses to the archaeological record. For the purpose of this work, we have explored the potential for modern and historic landscape characterisation of Zanzibar using maps, various satellite image platforms, and aerial imagery from our own and other projects low-altitude drone flights.

6.1 | Satellite imagery

In attempting to identify image and map sources for HLC at the site, we found that the quantity and quality of historic and suitably high-resolution satellite imagery available and relevant for the survey area were lacking, and we put this down to a lack of focussed interest in satellite survey of Eastern Africa in comparison to modern historical hotspots in North America and Europe, North Africa, the Mediterranean and the Middle East, or of Russia and the former states of the Soviet Union. Archaeological surveys of Mesopotamia or Europe, for example, may draw on a significant quantity of high-resolution satellite imagery dating back to the CORONA spy satellite missions of 1959–1972. By comparison, the only high-resolution frames of CORONA imagery of Zanzibar date to 1965–1966 (EROS, 2018) following the 1964 Zanzibar Revolution, and during a period of political and economic investment in the country by the German Democratic Republic and China (Burgess, 2021; Speller, 2007; Welliver et al., 1992).

By comparison, the availability of current imagery has improved significantly in the past few years. Very high-resolution (~1–15 m) and high-resolution (~30 m) satellite imagery is available from a range of government agencies (e.g. NASA and ESA) and commercial organisations (e.g. Planet.com). These offer an extensive library of imagery related to the modern landscape, and examples of relevant historic imagery which can be downloaded or purchased at processing costs. High-resolution imagery, including historic imagery of the past 30–40 years, is also freely available through composite portals such as Google Earth and Microsoft Bing maps. However, historic characterisation using composite sources is complicated by the mosaicking of imagery from different sources and dates to achieve the best ground view, and the subsequent masking of image metadata related to original capture dates, resolution and processing. 'Moderate' resolution Landsat imagery (ranging from 80 m multispectral Landsat 1 imagery in 1972 to 15 m panchromatic in current Landsat 8 imagery) is available with global coverage from United States Geological Survey (USGS) dating back to 1972 (Goward et al., 2006: 1157), but this imagery is intended for large-scale landscape characterisation and is not detailed enough for fine-grained archaeological site reconnaissance.

In order to map recent landscape changes from satellite imagery, we imported suitable frames of high- and very high-resolution satellite imagery into our GIS and georectified against a 2017 fixed-wing drone survey of Zanzibar carried out by the ZanSea Mapping Initiative (ZMI) (Barthelemy & Juma, 2017). Potential archaeological remains and visible landscape features such as shorelines, woodland, plantations, mangroves, grass and scrubland, coral outcrops, walls and enclosures, roads, buildings, wells, and cisterns, standing archaeological remains and individually identifiable trees, such as baobabs, mangoes, and coconuts, were then traced and plotted in shapefiles according to each image to enable comparison and identify change over the past 50 years. Our own GPS surveys, photographic, and recorded field observations, as well as archaeological and conservation publications provided some qualitative control to the interpretation of this imagery. The results of our satellite-mapping exercise of Unguja Ukuu can be seen in Figure 11.

The CORONA imagery analysed for this project was a frame from the CORONA KH-4A missions, captured in 1965. This system featured a camera with a theoretical ground resolution of 2.75 m, but photographic considerations such as lens quality and fogging (of either lens or film), atmospheric conditions and secondary processing related to the digital scanning of original photographic film frames mean that fine detail features up to 10 m in size are not always clearly identifiable. It was possible to estimate broad landscape characteristics and to create polygons of areas of woodland, scrubland or

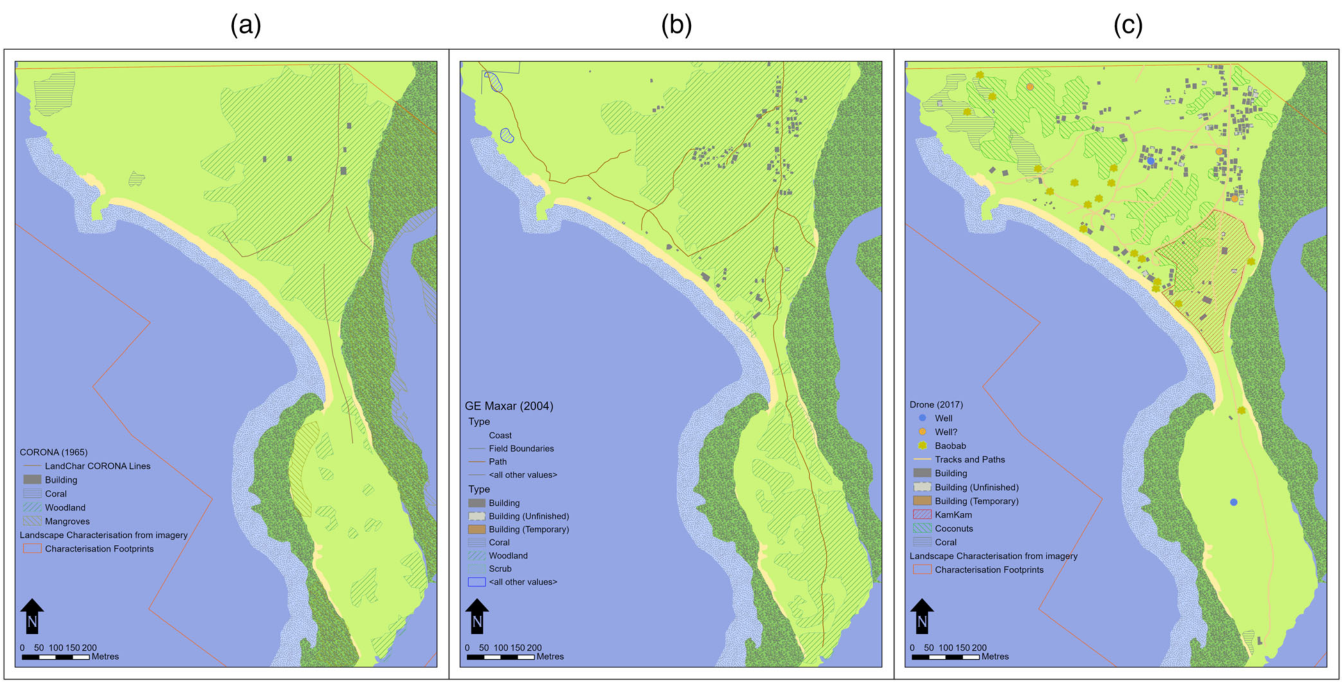


FIGURE 11 Comparative images of landscape characterisation mapping from (a) CORONA imagery (1964), (b) MAXAR satellite imagery from Google Earth (2004) and (c) quadcopter drone photogrammetry survey (2017) [Colour figure can be viewed at wileyonlinelibrary.com]

shrubland, mangroves, open ground and beaches, but the identification of woodland type and tree species was not possible. As might be expected for a reconnaissance satellite, mapping of human activity features that required land clearance, such as roads or occupation areas, was found to be reliable, although the resolution was not high enough to identify individual houses or structures within these areas.

Although it was not possible to identify small ground features, this was the earliest aerial imagery available for the survey area and therefore provided our baseline for identifying broad landscape changes in the recent history of the site.

Composite MAXAR images with a ground resolution of approximately 60 cm captured in 2004, 2013 and 2017 provided a useful series capturing landscape change within the past 20 years. The resolution of these images was good enough to map fine landscape details, such as individual structures and walls, areas of cultivation and coral outcrops, and to identify some individual tree species to plot coconut plantations as well as baobabs. By comparison with our own GPS survey, variable seasonal growth baobabs with leaf cover were not always reliably distinguishable from mango trees.

The very high resolution of these images also made it possible to identify and compare soil and crop marks in order to make some assessment of whether they represent one-off features related to events in a given year or to long-term ground conditions that might indicate subsurface geological or archaeological features. This type of comparison was found to be an effective tool in a previous survey of Fukuchani to the north (Fitton, 2017).

Sentinel-2 is a multispectral environmental observation satellite designed for high-resolution landscape monitoring. Imagery is recorded digitally from 13 wavelength bands in the visible/near infrared (VNIR) and short-wave infrared spectral range (SWIR), and these frames can then be combined in order to produce imagery useful for a range of analytical purposes. Sentinel imagery has varying maximum resolutions ranging from 10 m in the visible and NIR spectrum, dropping to 20 m for VNIR wavelengths and 60 m for specific water-vapour sensitive bands. Although these resolutions were deemed too low for identification of structural features, experimentation with combinations of VNIR and NIR wavelengths suggests it might be possible to identify broader features for site distribution plotting.

We obtained frames from Sentinel Hub and carried out comparative analysis of Sentinel-2 multispectral imagery captured during dry and wet seasons to aid characterisation of different vegetation and soil types, and to try to identify anomalous vegetation growth and soil marks in areas of known buried archaeological remains. This provides both a tool for predicting locations for archaeological potential and a way of characterising the soils/vegetation types potentially associated with anthropogenic soils. The imagery proved useful in distinguishing between different types of vegetation cover. We found, however, that ESA recommended wavelength combinations were not entirely reliable for the purpose, perhaps because of differences in the types of vegetation being observed compared to those in calibration case study areas. Two areas of possible correlation were noted between anomalous soil reflectance in band combinations 8a-8-11 and 12-4-2 (Geology) with buried anthropogenic soil types based on UETZAP STP sampling (Figure 12). The sampled images were captured during our field season and compared to

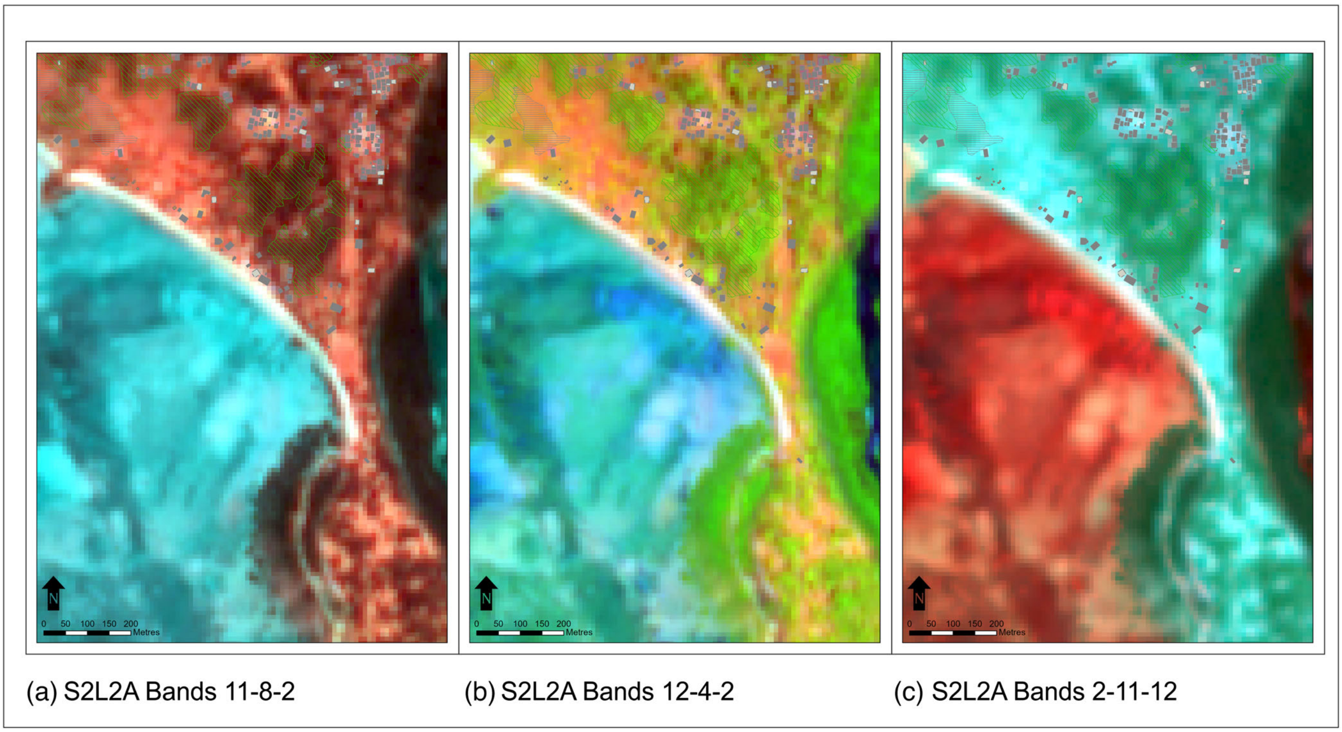


FIGURE 12 Comparative multispectral imagery from Sentinel-2 satellite referred to in text [Colour figure can be viewed at wileyonlinelibrary.com]

alternative season data, but given the dense woodland covering some other sample locations, we cannot yet rule out the possibility of coincidence related to ground clearance, and we await geochemical test results to further test this possibility.

Sentinel-2 proved particularly valuable, however, in distinguishing between different sediments and conditions in the intertidal zone and shallow water environments. Minor adjustments to Sentinel-2 wavelength band combinations were found to aid delimitation of the boundaries between, for example, dense woodland along the shoreline and mangroves with their roots in the intertidal zone; between open water and the sediment-rich mangrove creek; and between areas of sand and shallow or deep deposits of sediment overlying coral platforms. By comparing this imagery to the much lower resolution geological maps of the wider coastline, we have been able to greatly improve our map of the potential marine resource areas around Unguja Ukuu, which provide a point of comparison to our ongoing investigation of the origins of archaeological remains found across the site itself. Through this analysis, we have also identified several anomalous features visible in satellite imagery tangential to visible geological, hydrological or vegetative features, and which are not mapped in existing databases such as the Allen Coral Atlas. Some of these features correlate, however, with intertidal routeways observed during fieldwork and may therefore represent trampled causeways created by regular foot traffic across the coral shelf (Figure 13).

6.2 | Satellite mapping results

The primary aim of our satellite mapping exercise was to characterise the current landscape and recent changes as a background for understanding the archaeological record and also as a means of identifying past features through topographic and vegetation indicators. Landscape characterisation was based on successive satellite images, supported by reference to survey maps created from ground survey and unidentified aerial images in the 1980s and 1990s, which demonstrate the steady growth of the modern settlement since the 1960s (Figure 11). Clearance related to the settlement was apparent regardless of seasonal growth, albeit to varying degrees, but details such as individual structures were not always clearly visible. The growth of the 1960s settlement was apparently accompanied by a steady reduction of the dense woodland to be replaced by coconut plantations, and smaller, lighter vegetation on ground that today is for cultivation. Although it was sometimes possible to map a certain portion of large surface features such as areas of exposed coral bedrock, significant variation of even low-level seasonal grass and scrub means that these features are not always visible.

Mapping of potential landscape resource areas from each of the satellite image sources includes woodland, which on-site survey has confirmed is secondary regrowth across the archaeological site, exposed coral bedrock, grass and shrublands, mangroves, seasonal

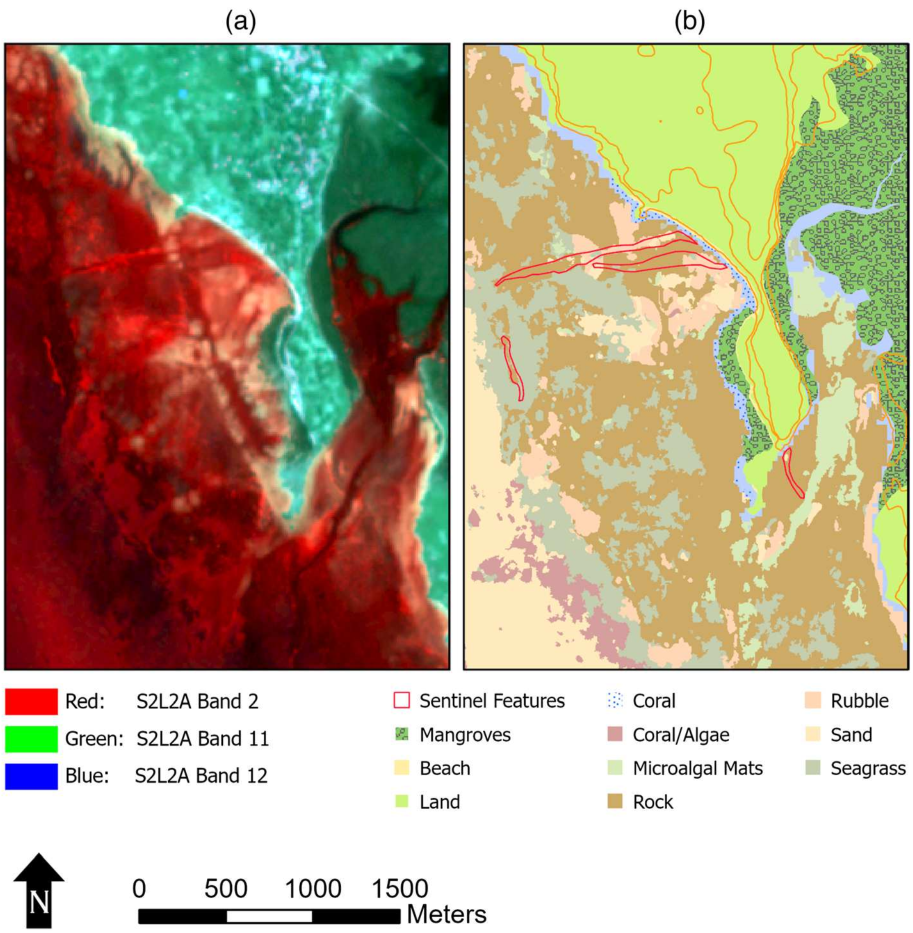


FIGURE 13 Comparative images of (a) custom Sentinel-2 multispectral waveband combination (bands 2-11-12) and (b) landscape characterisation derived from satellite imagery and Allen coral database. Note the areas of possible intertidal pedestrian routeways visible in Sentinel-2 image but not mapped in standard databases or analysis of standard waveband combinations [Colour figure can be viewed at wileyonlinelibrary.com]

watercourses, intertidal platforms and shallow water reefs (Figure 11). Modern features such as buildings, roads, infrastructures, cultivated fields and plantations that cover the majority of the area today are not marked in these maps. The variability of resource visibility in the different sources is due in some cases to the relevant technical specifications and resolution of the camera and satellite, but in others to atmospheric and environmental conditions and seasonal growth.

6.3 | Drone survey

With access to either a quadcopter or a fixed-wing drone and a good-quality digital camera, high-resolution photo surveys can be flown at low elevation (30–120 m) and used as the basis of photogrammetry to construct orthorectified aerial imagery of the ground and DTMs of the topographic surface, including structures and features such as trees and substantial vegetation. Repeat surveys in different seasons will also provide imagery of ground features under different seasonal and environmental conditions, improving the odds of identifying ground features and models of the surface with minimal ground cover.

We have used three sets of aerial imagery captured from drone flights: imagery from the Zanzibar Mapping Initiative (ZMI) captured in November 2016 using a fixed-wing drone (Anon); a quadcopter survey of Unguja Ukuu flown by Horton's team in July 2017; and an additional quadcopter survey flown in October 2019. We therefore have imagery from three seasons under different environmental conditions, and captured two years apart, providing multi-year observations of urban growth and landscape change between 2016 and 2019.

We have applied the same landscape characterisation scheme developed for our satellite analysis to the three sets of drone imagery. The legal low-altitude flight of the drone survey (max 120 m) offers a very high-resolution set of survey imagery for analysis, and mapping of ground features visible in the optical spectrum is of course far easier than using satellite imagery. Despite this, however, we still note limitations related to the environment which archaeological surveyors should be aware of. The high-quality camera used by the ZMI offered an excellent estimated ground resolution in the survey region of approximately 7 cm (Open Aerial Map). Using this imagery, it has been possible to map features not identifiable even in very high-resolution satellite imagery from MAXAR. The ZMI imagery enabled mapping of small features such as buildings, wells and cisterns, small paths as well as roads, known standing archaeological remains, individual baobab and mango trees, and even the outlines of trenches and spoil upcast from our test pits and STPs. On Uzi Island, for example, we noted what appears to be the retaining wall of a cemetery to the west of the modern town at the northern end of the island, which was originally recorded in an offsite landscape survey (Juma, 2004). This site was not consistently visible in recent aerial imagery, not at all in satellite imagery, and has not previously been precisely mapped (Figure 14). The results again demonstrate

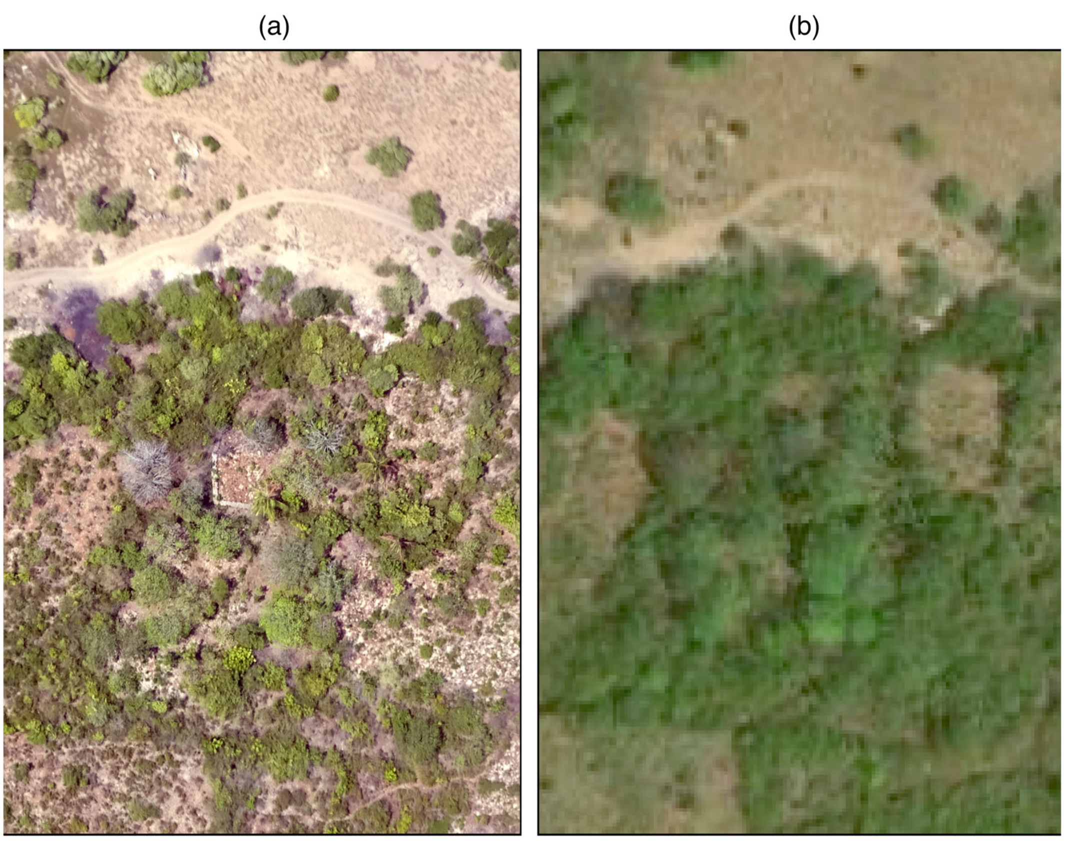


FIGURE 14 Comparative images from (a) ZMI fixed-wing drone survey and (b) MAXAR satellite image showing variable seasonal visibility of unmapped cemetery retaining wall on Uzi Island. ZMI, Zanzibar Mapping Initiative [Colour figure can be viewed at wileyonlinelibrary.com]

that even potentially modern settlement features which are not a daily priority activity area can appear and disappear in satellite imagery under seasonal growth, but that good quality drone imagery offers the best possible aerial compliment to ground survey.

6.4 | Ground survey and excavation

Building on our spatial analysis of auger core inclusions, we conducted STP surveys in two areas to test the hypothesised continuity of archaeological remains between coring transects and as a guide for positioning excavation trenches to explore domestic structures. We also continued excavating STPs along east–west transects to the north and south of the settlement, allowing us to expand on previous studies by exploring areas of activity possibly relating to agricultural fields or resource areas in the surrounding landscape.

In the western part of the settlement site, our STP survey confirmed the hypothesised presence of architectural materials and a cluster of daub housing, and enabled us to reliably position our excavation trench directly across the buried remains of a burned and collapsed daub house with no visible surface artefacts. In the area south of the Kam-Kam, STPs confirmed the presence of at least 1 m of midden deposits at 10–20 cm below disturbed topsoil, despite the earlier bulldozing of the parade ground and associated destruction of archaeological contexts. Our off-site, STP transects detected two further potential occupation or activity areas, contemporary to the ancient town, at some distance beyond the previously estimated limit of settlement and visible surface remains. We also recorded a series of low-profile topographic mounds approximately 5–10 m in diameter beneath the undergrowth in a densely wooded area of the 'northern central' area of the site. We hypothesise that these mounds represent a further cluster of collapsed daub structures, and post-excavation

FIGURE 15 New historic landscape characterisation map of archaeological 6th–15th century occupation areas, hypothesised mosque remains and middens across the local landscape of Unguja Ukuu [Colour figure can be viewed at wileyonlinelibrary.com]

GIS analysis confirms a spatial correlation between this group and one of the larger clusters of daub in the northern part of the original auger survey area (Figure 15).

Excavation of domestic structures at Unguja Ukuu has also revealed an intense temporality to the settlement. Detailed C14 dating of a daub structure on the eastern edge of the site has shown that it was rebuilt twice in the course of less than a century (Wynne-Jones et al., 2021). It has become customary to discuss the 7th–10th centuries on Zanzibar—and indeed the entire coast—as a single chronological moment, since artefact assemblages change little throughout this period and thus temporal detail is difficult to obtain. Yet this excavation has raised the possibility of relatively brief and intense phases of occupation at the site. It also raises questions about the site layout, which as described above has clusters of houses and activity areas with some spaces between. It is possible that these were occupied at different times: rather than a single sprawling site there may have been a fluctuating occupation of a larger area (Figure 15). Excavations thus provide a guide to the ways we can interpret the spatial data.

Likewise, the analysis of artefact data from excavations informs some of the ways space is understood. The general distribution of small-scale iron smithing debris is spread across the domestic deposits at Unguja Ukuu, suggesting that ironworking was happening between domestic areas and in multiple locations (Bauzyté, 2019). This fits into a pattern where small-scale craft working can be identified in the areas immediately outside daub structures through careful contextual excavation. The cluster of high magnetic readings recorded in the area of the bulldozed parade ground (Fitton & Wynne-Jones, 2017) necessitates a modification of this hypothesis, but the spread and variety of metal items recovered from this area by metal detection (mostly damaged copper–alloy artefacts including fragments of a bracelet, a flask cap, sealed tubular container, fragments of plate metal and rivets and several lead fishing weights) suggest that the latter was either a special purpose location (such as for market trade) or that it might have been a dump for iron slag and debris from working locations across the settlement.

Ground truthing of the data from remote sensing and GIS mapping therefore provides an important contribution to the ways we interpret spatial patterning. It can confirm broad patterns identified and also show the ways that reliance on single technique mapping fails to capture detail of the site. Of particular relevance, we note the fact that even in post-excavation reanalysis of our GIS, none of the field observations of surface sherd scatters, structural mounds, or eroding daub remains were visible in either visible or multi-spectral satellite imagery. This appears to be due to the combination of vegetation and foliage covering the site (even in winter); the low-profile of topographic anomalies; and the complication of modern site disturbances and intrusions. This means that although in multispectral imagery some minor variations can be seen in the area of the site compared to the surrounding landscape, it has not yet been possible to determine whether this is due to archaeological deposits or modern occupation. This was true even for very high-resolution satellite imagery captured during our survey season, although it was possible to identify our working areas and excavation trenches. Further testing and comparison to other sites across the island might be able to identify waveband combinations to help identify areas of interest for ground truthing. Ground truthing can also provide important contextual information regarding site chronology, artefact patterning and activity, which feed back into the ways we understand the archaeological space. In this regard, we note the success so far of our historic landscape characterisation, which has allowed us to prioritise and target areas of the settlement landscape for survey, and to contextualise our field data in post-excavation analysis in the light of complementary information.

7 | GIS EVALUATION OF REMOTE SENSING AND GROUND SURVEY DATA

From our historical characterisation analysis of the site from both satellite imagery and legacy data so far, it is clear that the terrestrial landscapes of Unguja Ukuu have changed even in the past 60 years. The growth of the modern village of Unguja Ukuu Kaepwani recorded in historic maps has been accompanied by the spread of associated but outlying houses and farms and by the ground clearance for both urban infrastructure such as roads and electricity pylons and by the cultivation of a wide agricultural hinterland of small gardens, fenced allotments, hand-ploughed fields and coconut plantations that replaced dense, mixed, secondary woodland covering most of the remains of the archaeological site. These changes are visible (albeit to varying degrees) in the chronological characterisation of historic and recent satellite imagery (Figure 11), and apparently fits a trend of clearance and cultivation in the hinterlands of other villages established by the Revolutionary Government of Zanzibar after 1964 (Singer, 1996).

In contrast with the immediate area of Unguja Ukuu Kaepwani, the peninsula of Ras Makime appears to have been relatively unchanged by the landscape processes of the late 20th century. The remains of recent coral limekilns are visible along the eastern shoreline of this peninsula, but clearance of scrub and woodland has been minimal apart from the cultivation of several large, ploughed fields sometime between 1980 and 2003 (Khamis Ali, personal communication 2014). Furthermore, apart from a small 17th–19th century cemetery reported on the western cliffs and a single scatter of (undiagnostic) sherds recorded on the western shoreline, our survey and STPs across this peninsula has not shown any indications of occupation activity or evidence of permanent settlement of any period. We hypothesise that the area of Ras Mkumbe may have been maintained in various periods as scrubland with small areas of trees for grazing and resources.

It is clear from the comparison of source datasets that the resolution, quality and quantity of satellite imagery available for the observation of the Zanzibar Archipelago has improved considerably within the past decade, and that remote sensing using satellite imagery can now be used to obtain a broad picture of contemporary landscapes on the coast. Based on our observations in our survey area, we have compiled a table of potentially useful archaeological and environmental features visible in the different source datasets, and which are likely to be visible in similar tropical and sub-Saharan coastal contexts (Table 1). However, comparison between capture dates demonstrates

TABLE 1 Archaeological, environmental and landscape features visible and detectable in relevant datasets for cross-referenced site survey on Zanzibar

Dataset	Soil cover	Vegetation cover	Water sources	Coral	Archaeological features	Modern structures	Modern land-use
CORONA KH-4A Satellite Imagery (1965)	Ground clearance	Woodland; mangroves; scrubland	Lakes; Rivers	Exposed coral bedrock	Standing remains larger than 10 m	Structures larger than 10 m	Field systems; settlements; roads
MAXAR Satellite Imagery (2004, 2013, 2017)	Ground clearance	Woodland; mangroves; scrubland; tree types (baobabs, mangos)	Wells; cisterns	Exposed coral bedrock	Standing remains larger than 2 m	Structures larger than 2 m; electrical pylons	Cultivation; field systems; aquaculture (seaweed farms); settlements and infrastructure; roads and trackways
Sentinel-2 Multispectral Satellite Imagery (2017, 2019)	Ground clearance	Woodland; mangroves; scrubland;		Exposed coral bedrock	Standing remains larger than 2 m	Structures larger than 2 m	Cultivation; field systems; settlements and infrastructure; roads and trackways
Drone survey (2016, 2017, 2019)		Woodland; mangroves; tree types (baobabs, mangos, etc); farming plots	Wells, cisterns, rivers	Coral outcrops	Structural remains >50 cm, soil marks	Structures, field boundaries, roads	
Landscape survey	Topsoil and subsoils	Woodland; mangroves; tree types (baobabs, mangos, etc); farming plots	Wells, cisterns, watercourses	Outcrops; surface scatter/coral rag	Settlement; waste middens; resource processing (metal working, shell middens)		
Excavation	Topsoil and buried archaeological sediments	Surface and buried palaeoenvironmental indicators	Wells	Coral rag	Daub, timber, coral structures; waste middens, burials, activity surfaces, etc.		

the significant seasonal variability of groundcover and consequently the visibility of archaeological landscape features. Based on our analysis so far, though we have found little or no correlation between the features of the modern terrestrial landscape observed from satellite imagery with excavated archaeological contexts. Although the technique remains a valuable tool and method of survey in more open vegetation landscapes then, given the density of vegetation and impact of the urban settlement on this landscape, remote sensing cannot be used as a guide to the palaeolandscapes that would have been contemporary with the past occupation of the site. Drone mapping was similarly inadequate for the investigation of palaeolandscapes, although the increased image resolution enabled rapid identification and recording of small surface features including previously reported but unmapped historic structures. Cross-referencing of imagery (especially with ground-truthed datasets) was essential therefore to the identification of potential archaeological features from these sources. We remain hopeful, however, that as we continue to develop a greater understanding of the spatial distribution of archaeological activities and modern landscape characteristics in the archipelago, we may also be able to develop a model for predicting site locations based on soil spectra, vegetation and topographic indicators for identification from aerial and satellite imagery.

In contrast with the remote sensing data, however, integration and reanalysis of legacy data in the GIS, especially in comparison to new surveys, has enabled us to identify new patterns of settlement and landscape use in archived materials. Our STP surveys and targeted excavations have been crucial in exploring what the data means, culturally, spatially and chronologically, not because they are technically revolutionary but because they have opened a new window and perspective on complementary material. The integration of Juma's (2004) earlier coring survey, for example, has enabled us to explore the archaeological and taphonomic history of the landscape in a way that the historic landscape characterisation of satellite imagery and maps has not.

Systematic mapping of these core samples and our subsequent re-evaluation of this dataset focussing on inclusions enables a new vision of the layout of the site. Rather than representing a single, homogenous area of occupation across the entire landscape, it becomes possible to view the site layout through clusters of architectural debris, their associated middens. Interestingly, open spaces emerge between the clusters, suggesting that different areas were associated with different activities. Geophysical survey and the identification of clusters of magnetic anomalies indicate potential crafting and ironworking in some of these open spaces. Most notably, evidence for ironworking was concentrated in one of the 'open' spaces towards the SW of the site (Fitton & Wynne-Jones, 2017). This has been discussed as being part of the maritime landscape of Unguja Ukuu—ironworking was a key resource for a harbour and shipbuilding space—but is also positioned within the occupation area of the settlement. Excavations and STP surveys further refined what it is possible to say about these patterns, including providing important chronological considerations and a deeper consideration of how craft activity was patterned in space.

Elevation and coordinate data for each of the cores have provided the basis of an alternative topographic model using data collected prior to the reshaping of the landscape during construction of the Kam-Kam, which has allowed us to calculate an estimated quantity and depth of topsoil lost to the bulldozing of the parade ground. This comparison has consequently enabled us to compare the stratigraphic record of STPs from UETZAP to both Juma's (2004) auger cores and to Horton and Clark's test pits (1985a), and confirm that buried contexts below approximately 10–20 cm across this area today remain relatively secure (Figure 7). Similar comparisons of our trenches across the site to cross-sections compiled from auger core profiles compiled in geological modelling software are also being used to re-evaluate the temporal and spatial distribution of archaeological inclusions and contexts across this landscape. The same geological model has also been used to confirm that sand deposits on the eastern edge of the site are natural and deep, and may mark a natural break in the spatial layout of the site, rather than erosion and loss of archaeological deposits.

Inclusions recorded in the auger core archive correlate with our identification of a number of low mounds in the northern part of the archaeological site and indicate that this area may represent a first millennium occupation area, and perhaps the origin of one of Horton and Clark's (1985a) mapped middens. Similar areas of midden material and possible platforms were also identified to the north beyond the limits of the earlier surveys in the 1980s and 1990s, and imply that a sporadic occupation of the landscape continues beyond the 'core' area of the site we have previously explored (Figure 15).

The integration of Juma's (2004) earlier resistivity survey has also provided a useful complementary dataset to evaluate surface soil and vegetation marks, and near-surface archaeological or geological deposits. As noted above, comparison of the resistivity survey and core inclusions indicates a correlation between records of daub and coral with a high-resistance anomaly beneath what is now a beach resort on the shoreline of Menai Bay (Figure 10). Comparison indicates a further correlation of a high-resistance anomaly at the north-western limit of the resistivity survey area with a sub-circular area mapped during our 2019 field survey and from our Very High Resolution (VHR) drone imagery as a near-surface coral exposure. The apparent similarity in size of this feature with the nearby potential mosque discovered by Juma, and proximity to known archaeological features, including surface and sub-surface deposits of burned daub in our 2019 STPs, and the anomalous nature of this coral compared to the low resistance surrounding area evidenced in the resistivity survey indicate that this may not be a natural deposit but perhaps the archaeological remains of a collapsed structure. The correlation therefore provides a useful basis for evaluating similar, relatively small visual features in our database of VHR drone imagery and flagging as possible archaeological features, and was only made possible by the integration and comparison of multiple datasets. As outlined above, this identification of potential archaeological features, even in drone imagery, was not found to be reliable in the absence of complementary archaeological ground survey data.

8 | CONCLUSIONS

The results of our analysis so far demonstrate the importance and in this context the need for combined approaches to archaeological survey to best investigate and understand past settlements within both current and palaeolandscape settings. Given the availability of suitably high-resolution and high-quality imagery for the purpose of remote sensing offers a range of powerful tools for considering sites in the context of topography, hydrology and vegetation, and given appropriate environmental conditions, it offers a relatively quick and cheap way of exploring a new region. As such, the suite of tools and techniques has driven a spatial turn in the archaeology of many regions. The results presented here demonstrate, however, that the use of remote sensing alone for archaeological survey in the context of the Swahili Coast is not currently an efficient approach, and that complementary ground survey data are required to provide interpretative support. Although it may yet prove possible to identify soil marks or vegetative indicators related to past urban ecologies and archaeological activity areas in the vicinity of a site in the region, this has not been possible in the landscape around Unguja Ukuu. Buried archaeological features smaller than site level are not visible in satellite imagery of the survey universe, and even in relatively low-altitude drone imagery, such features are not reliably visible from season to season because of the density of vegetation and speed of growth in this environment.

This is not to undermine the role of remote sensing for archaeological survey in the region though. Integration of our own fieldwork, survey and excavation results in a GIS alongside legacy archaeological data and a broad range of complementary datasets has allowed us to explore the site in the context of the greatest possible range of spatial information. At Unguja Ukuu, this includes data extrapolated and inferred from coring surveys, geophysical surveys, geological maps and remote sensing. Even with this dataset, it remains important to emphasise that remote sensing is based on a mapping of the modern landscape, and this will not always be the same as the palaeolandscape. Our own landscape regression exercise at this single site on Zanzibar has shown significant change even in the past six decades, and our field observations demonstrate that some of these changes have had a significant impact on the archaeological record. That being said, we have been able to identify and map environmental features for further investigation, including coral outcrops and lateritic deposits that contribute to our understanding of the natural availability of such resources in the landscape around the site, as well as topographic and geological features that may indicate archaeological quarries. A combination of spatial techniques, building towards a database of known historic, archaeological and archaeologically relevant or adjacent landscape features, offers the strongest means of creating an interpretation of a site in its landscape that is more than the sum of its parts. In this case, it has enabled us to identify a lower density settlement plan than previously interpreted based on the extent of surface material and to begin to discuss practical, social and cultural motivations which might have shaped this model.

The assessment and comparison of multiple datasets derived from different sources and techniques for the study of the site at Unguja Ukuu has enabled us to compose a chart (Table 1) to support initial identification and cross-referencing of features of archaeological interest in Eastern Africa. As noted above, regional and period variations in archaeological remains, local landscapes, and environmental and climatic conditions mean that this table may not be universally applicable, but we believe it may also offer a useful shorthand for the ways in which ground and remote datasets can be compared and contrasted to explore different types and scales of features across sub-Saharan Africa, and in similar tropical and coastal environments beyond the immediate region of Zanzibar.

ACKNOWLEDGEMENTS

We were assisted during fieldwork at Unguja Ukuu by the Zanzibar Department of Antiquities, notably Abdallah Khamis Ali (Director of Antiquities) and Dr Amina Issa (Director of Museums and Antiquities). We are also grateful for the assistance and permissions given by the SMZ. All our local community assistants were crucial to the success of the project, particularly Naim, Salim Suha and Abdullah for survey and excavation assistance, and Mwana Heri provided invaluable local support. We are grateful to Dr Elinaza Mjema at UDSM for his support and for helping us to find student volunteers.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author, TF, upon reasonable request.

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How to cite this article: Fitton, T., Sulas, F., Lisowski, M., Alexander, M., Juma, A., & Wynne-Jones, S. (2022). Integrating spatial and legacy data to understand archaeological sites in their landscape. A case study from Unguja Ukuu, Zanzibar. *Archaeological Prospection*, 1–24. https://doi.org/10.1002/arp.1885