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Climate-smart harvesting and storing of water: The legacy of *dhaka* pits at Great Zimbabwe

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ABSTRACT

Understanding past water management is crucial to address contemporary human-environmental challenges in sub-Saharan Africa, where urban growth is impacting upon water availability and supply. This study integrates soil profiles, high-resolution topographic data, historical sources, and socioecological memory to reconstruct how the ancient urban society at Great Zimbabwe negotiated water security. New evidence shows for the first time that closed depressions known as *dhaka* pits were used by the inhabitants of Great Zimbabwe for water storage and harvesting for a long time, possibly since the emergence of settlement in the mid-second millennium CE. These pits were part of a landscape-scale water management system that exploited catchment hydrology and groundwater by means of artificial *dhaka* reservoirs, wells, and springs to secure water for subsistence, farming, ritual and ceremony services. This study highlights the need for precise dating of the construction and functioning period of this water management system at Great Zimbabwe. Understanding past water management in such a water-scarce region is important for reconstructing how the ancient Great Zimbabwe urban society negotiated water security, but also for understanding contemporary human-environmental challenges.

1. Introduction

Water security is amongst the greatest global challenges for human subsistence and environmental health. Developing effective strategies is urgent due to increasing population and severe anthropogenic climate change (Rockström et al., 2014; Gillson et al., 2021). Africa is amongst the continents struggling to secure freshwater for human subsistence, environmental health, and economic development (Rodell et al., 2018). Despite the presence of abundant and diverse water resources, water supply for basic needs such as drinking, health and food production is a

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challenge. The archaeological site of Great Zimbabwe presents evidence of how past societies confronted with such challenges in a context dominated by climate change.

Great Zimbabwe is an architectural ensemble clustered on, and around, a hill and adjacent valleys, located in the southern margins of the Zimbabwe plateau (Fig. 1). It is dominated by stone monumental architecture with the Hill, Great Enclosure and Valley complexes making the core of what was once a thriving ancient city. Several earthen residential and other structures are found insite and outside the monumental complexes (Garlake, 1973). Established in the 11th century CE, Great Zimbabwe rose as an urban centre and capital of a vast state in southern Africa (Chirikure et al., 2013, 2018). Its size, function, and eventual demise are a subject of both public speculation and increasing scientific investigation (Pikirayi, 2017). The rise and development of Great Zimbabwe fall within periods associated with both wetter and drier climatic conditions, namely the Medieval Climatic Anomaly (950–1250 CE) and the Little Ice Age (1300–1850 CE). While these conditions might not have been globally uniform, the demise of Great Zimbabwe might be linked to the Little Ice Age (Holmgren and Öberg, 2006). This paper presents new research findings concerning the site and resource management strategies that supported it with a view to exposing their impact and legacies on the present landscape.

For over a century, archaeological research at Great Zimbabwe sought to understand the architecture, material culture distribution, use of space, past vegetation types and patterns (see e.g., Chikumbirike et al., 2016; Chirikure et al., 2017, 2018; Musindo, 2019 and references therein). This paper draws on results from recent and ongoing mapping, which integrates geoarchaeological and ethnographic surveys, and airborne laser scanning (ALS) to understand features and structures within and outside the main settlement complexes, and to investigate local hydrological conditions in relation to them (Pikirayi et al., 2016; Sulas and Pikirayi, 2018). A particular focus of this research are sizable depressions, known locally as *dhaka* pits, which are found at the bottom of the Hill Complex and elsewhere. These features have long been linked to ancient clay extraction (e.g., Hall, 1905: 280, 314, 344–353; Summers, 1971: 280), but never investigated until now.

Great Zimbabwe is surrounded by, and overlooks, granodiorite hills, which define a watershed with several micro-catchments and drained by streams and small rivers (Fig. 2). The granite geology was exploited intensively to capture groundwater for use at the site—a practice still carried out today around Great Zimbabwe. These settings might have supported agriculture even under climatic conditions drier than the present day (Holmgren and Öberg, 2006). Recent research sought to determine where the residents of the ancient city fetched their water from and how they managed water resources. This paper engages with debates about water crises in Africa by examining the long-term history of water and settlement interplay at Great Zimbabwe to address the following questions: 1) how was water managed to sustain urban growth in the past?, 2) how were water resources managed in the context of variable climate?, and 3) how did water management relate to the functioning of Great Zimbabwe's urban landscape? To answer these questions, ground surveys focused on collecting relevant ethnographic data from local communities; geoarchaeological investigations examined local soil sequences associated with the development of the cultural landscape; and, remote sensing was employed to map water resources and reservoirs around Great Zimbabwe.

2. Materials and methods

Fieldwork was conducted intermittently between 2014 and 2019 to survey, identify and record landscape sequences and water sources in and around Great Zimbabwe (Fig. 1). The survey was adjusted to align to local hydrological features such as watercourses, springs, and marshlands, and to determine how these could have played a role in the development and functioning of the ancient city. Mapping of landforms around Great Zimbabwe combined desktop research, ethnographic and geoarchaeological surveys, and remotely sensed mapping data. These approaches were aimed at acquiring an accurate depiction and interpretation of landforms immediately around the core architectural complexes. Where it was deemed necessary to understand certain landforms such as hills and valleys, surveys were extended some 5–10 kilometres from the core settlement site. Airborne laser scanning (ALS) mapping was conducted in 2016/17 to determine the nature and extent of the stone-walled and other built environment at Great Zimbabwe, and

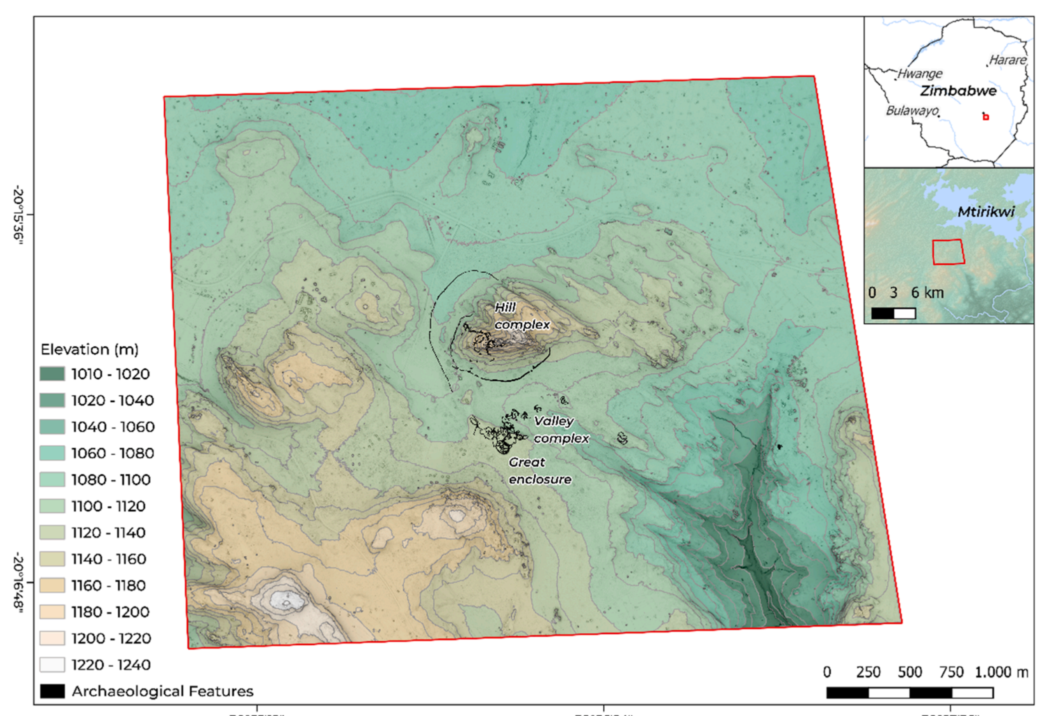

Fig. 1. Map of Great Zimbabwe showing the main archaeological complexes.

Fig. 2. Great Zimbabwe landscape: view of the core monumental area from the Hill Complex (left), and view of Mungwini area (right).

to detect how different landforms and *dhaka* pits were integrated into the ancient settlement.

Southern Africa has experienced warming over the last decades, and strong inter-annual and inter-decadal variability in rainfall patterns shows little evidence for substantial drying or wetting over the region (Davis-Reddy and Vincent, 2017). The climate of Great Zimbabwe is characterized by a distinct hot and dry season, a hot and wet season, and a warm and dry winter season (Chikumbirike et al., 2016). These semi-arid conditions might have also occurred during the 16th or 17th centuries CE.

2.1. Ground surveys: ethnography and geoarchaeology

An ethnographic approach was used to document the views of local communities (Bernard, 2006). This social, anthropological approach involved observing local community interactions with water, which were documented by way of themed interviews. This was vital for mapping water sources and soil types in their socioecological context, exposing traditional and economic values as well as social memories around changing hydrological conditions. Interviews with elders, living on the outskirts of the site, generated information on the types and distribution of water resources, their uses, management, and changes over time as well as related oral histories, traditions, and beliefs (Pikirayi, 2019). Based on this information, sites and features of

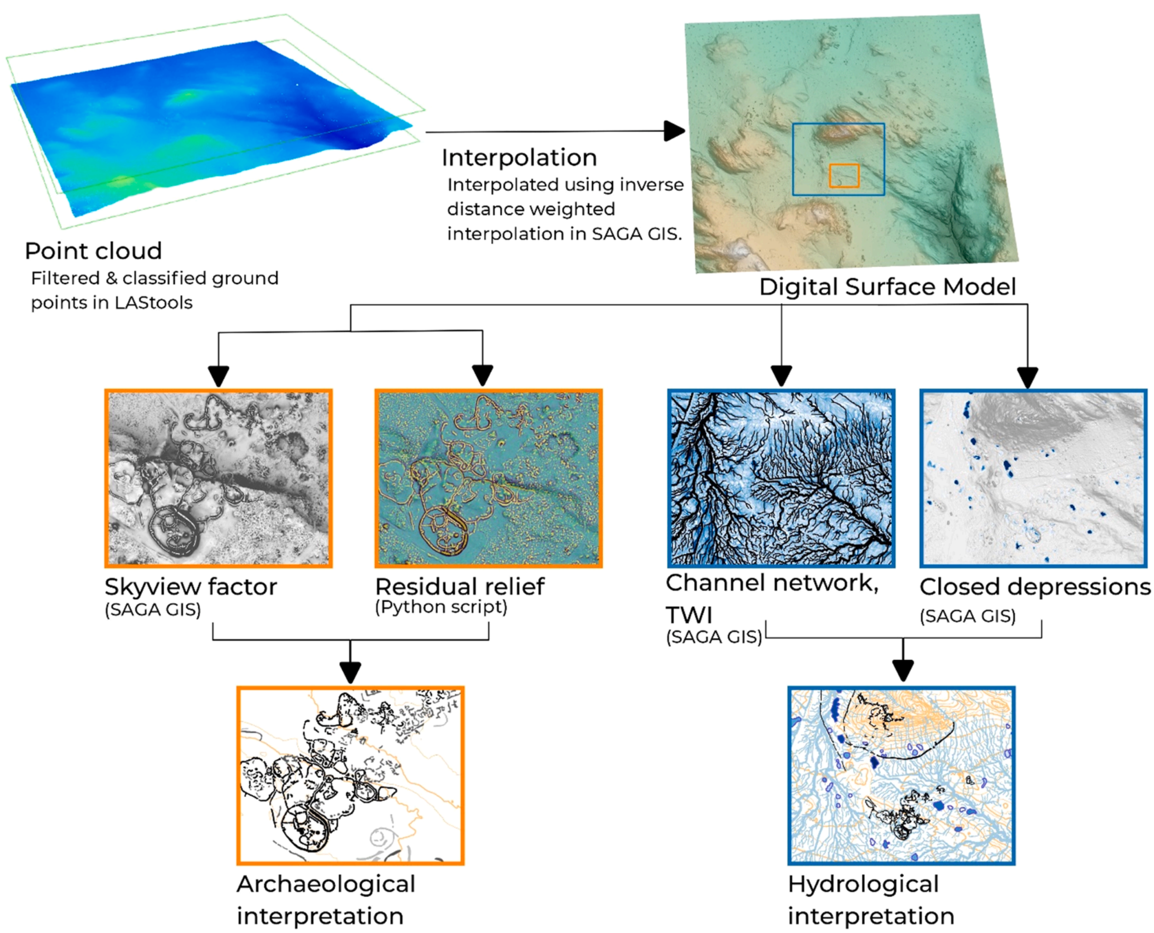

Fig. 3. Airborne laser scanning (ALS) mapping workflow.

interests, such as springs and areas with large depressions, were initially mapped using a global positioning system (GPS). In parallel, soil sequences were recorded and sampled from exposed sections and by digging test-pits within and outside the site complex. Deposits were sampled for soil multi-element chemical analysis by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICPAES) and archaeological soil micromorphology to characterise local soils and sediments, and to investigate landscape sequences. These analyses provided data to determine relations between soil properties, water availability and land management over time.

2.2. Remote sensing

Airborne laser scanning (ALS) and photographic survey mapped archaeological and hydrological features at and around Great Zimbabwe. ALS is ideal for this purpose, as it provides a detailed record of topography and is invaluable for investigating ancient urban areas (Stott et al., 2018), even when the ground is obscured by dense vegetation. To achieve this, the point cloud with a density of 4.8 points/m^2 was used to produce a Digital Terrain Model (DTM) raster with a spatial resolution of 0.4 m (Fig. 3) using the LAStools software package. This digital terrain model was used to derive visualisations that emphasise subtle, localised topographic changes, allowing detection of smaller archaeological features and structures such as collapsed walls, building foundations and cultivation fields. These include sky-view factor (Kokalj et al., 2011; Doneus, 2013), and residual relief modelling (Hiller and Smith, 2008; Doneus et al., 2008; Hesse, 2010; Kokalj and Hesse, 2017). These models were used in conjunction with high resolution colour orthophotography co-collected with the ALS data to identify and characterize archaeological features.

The digital terrain model was also used to perform surface hydrological analyses using SAGA software package (Gruber and Peckham, 2009; Olaya and Conrad, 2009), with emphasis on defining catchments and finding closed depressions that could be used to identify probable *dhaka* pits. The approximate volume of these pits was calculated using Qgis.

3. Results

3.1. Mapping local soil sequences

Geoarchaeological surveys recorded two main soil types in and around Great Zimbabwe. In the core area of the ancient city, the most common soil type is a dark brown, fine sand silty loam with fine charcoal and microcharcoal, and occasional potsherds. A second, less commonly observed, type is a red to reddish-brown, coarse to medium sand clayey loam that is found on lower hillsides such as around Rondavels, the lodges of the National Museums and Monuments of Zimbabwe (NMMZ) (Fig. 4).

In the core ancient area, soil profiles documented a generally consistent stratigraphic sequence, with minor localized variations (Table 1). The topsoil (20–30 cm thick) is a brown to dark brown, fine sand silty loam found above a dark to ashy brown, organic-rich sand silty loam subsoil horizon (over 40 cm thick). This horizon is characterized by indications of changing moisture levels, often appearing at the contact zone with the topsoil, and it rests directly on either granitic/basalt bedrock or red, sandy hillwash deposits.

3.2. Mapping of dhaka pits

Dhaka pits are large, circular depressions found primarily within the core site area. They have been interpreted as the result of quarrying

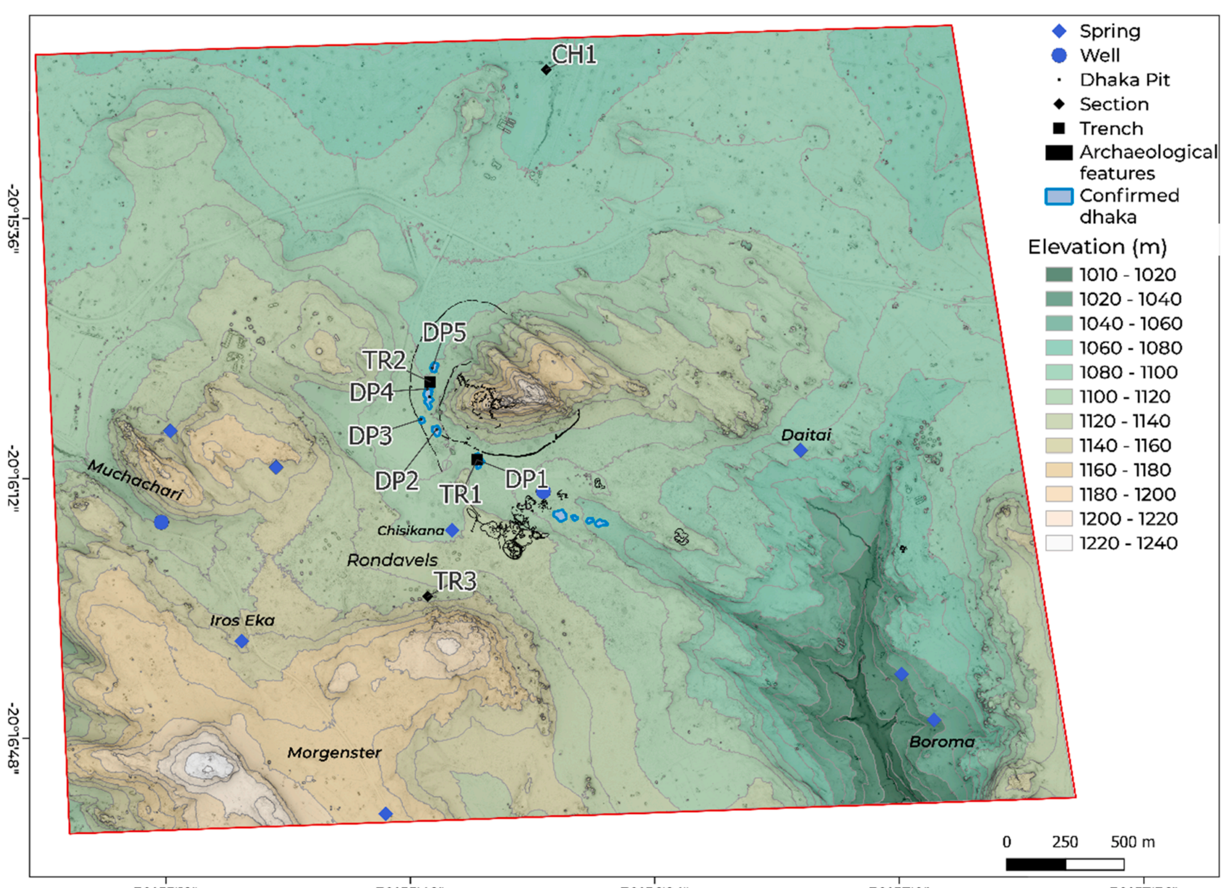

Fig. 4. Survey area showing the distribution of *dhaka* pits (DP), test trenches, sections, wells and springs recorded during the ground surveys.

Table 1
Local soil sequences and dhaka pit sequences. The location of the pits and trenches is shown in Fig. 4.

	Profile	Unit	Depth cm	Field description
	Section recorded along the mid-course of the Chisikana stream, draining a gently sloping stretch of land under thick riparian vegetation.			
LOCAL SOIL SEQUENCES	CH1	1	0–33	Dark brown (10YR 5/2) very fine sand silty loam; common fine and rare coarse rootlets; common burrowing; non distinct boundary – topsoil
		2	33–75	As above; occurrence of orangey mottles; diffuse boundary – aggrading alluvium
		3	75–165	Ashy dark brown (10YR 6/1) fine sand clayey loam with common fine quartz; diffuse boundary – buried alluvial soil.
		4	165–220 +	As above; increase in organic matter and bioturbation
	Section recorded inside the foundation pit of the new restaurant at the NMMZ Lodges (Rondavels).			
	TR3	1	0–20	Dark brown (10YR 3/1) fine sand silty loam; common fine rootlets; increased in compactness and rare coarse rootlets with depth; distinct boundary – topsoil
		2	20–70	Bright red (2.5YR 5/6) fine sand clayey loam with rare coarse sands and rootlets; dry and loose; distinct boundary – aggrading hillwash
		3	70–185 +	As above
	Two *dhaka* pits were explored via small test trenches (60 ×60 cm): TR1 in Dhaka Pit 1 and TR2 in Dhaka Pit 4.			
***DHAKA* PITS**	DP1-TR1	1	0–20	Dark brown (10YR 2/1–3/1) very fine sand silt loam; common fine rootlets and degrading organic matter; diffuse boundary - topsoil
		2	20–30	As above (10YR 2/1), slightly finer texture
		3	30–40	Dark brown fine sand silty loam with little clay; moister than above; microcharcoal; diffuse boundary - aggrading fine colluvium
		4	40–70 +	As above; increased clay content; 5 % iron-manganese mottles (c. 2–5 cm in diameter) – changing water table
	DP4-TR2	1	0–10	Dark brown (10YR 3/2) fine sand silty loam with coarse quartz and medium sands; common degrading organic matter; diffuse boundary – topsoil.
		2	20–30	Paler brown (10YR 3/3) fine sand silty loam with little clay and rare reddish fine sands; common fine rootlets; abundant organic matter; rare microcharcoal; diffuse boundary
		3	33–50	Reddish brown (5YR 4/6) medium to fine sands with common coarse sands; common orange and dark brown mottled – aggrading fine colluvium with changing soil moisture
		4	50–56 +	Bright orange (5YR 4/4) weathering bedrock

activity to supply clayey material for building houses (Hall, 1905: 280, 314, 344–353; Summers, 1971: 280; Garlake, 1973). Recent surveys located several *dhaka* pits at the foot of the Hill Complex, to the west and east of the Great Enclosure and on the slopes of Mutero Hill (Fig. 4). These pits straddle streams, of which some are blockaded by earthen dams.

Analysis of five pits along the southern-southwestern pediment of the Hill Complex showed that they have similar properties (Table 2): elliptical in shape, large in size (<40 ×10 m), have a visible cut reaching a depth of 1–2 m, with edges covered by thick bushes and trees, and reeds often growing inside them. For example, Dhaka Pits 1 and 2 on the southern pediment of the Hill Complex measure about 65 × 20 m, reaching a depth of 2 m (Fig. 5a). Thick bush and tree cover protects the edges, and a dark brown very fine soil is found at the bottom. Dhaka Pits 1–3 are well-spaced (c. 100 m apart), while Dhaka Pit 4 features three interconnected depressions along the strip-road of the Watergate area.

Georchaeological investigations at Dhaka Pits 1 and 4 revealed a relatively consistent soil sequence reaching a depth of 56–70 cm below the ground surface (Table 1). The topsoil is a reddish to dark brown very fine sand silty loam, reaching a depth of 10–30 cm, and covering a very dark brown to black, organic-rich very fine sandy and clayey silt. The dark brown to black soil reaches a depth of 50–70 cm and shows indications of soil redox changes (e.g., iron-manganese mottling).

Data from surveys, soil chemical and physical properties and local knowledge reveal links between the two soil types recorded and processes at work within Great Zimbabwe landscape. The red to reddish-brown sandy loam covering lower slopes is a young, incipient soil type—consistent with sandstone and granite-dominated landscapes. When exposed, especially on a gradient, sandstone and granite undergo erosion, producing hillwash deposits at the break of the slope. This soil type, thus, reflects localized and episodic land disruption upslope. In contrast, the core settlement area is covered by a dark brown sand silty loam, also observed in pockets beyond it. Its distribution, nature, and anthropogenic inclusions (e.g., potsherds, charcoal) suggest that this soil type is the footprint of Iron Age settlement and land use at Great Zimbabwe.

Soil data reflects changing soil moisture and localized episodes of groundwater table rising through time at Great Zimbabwe, and likely within its surroundings. These processes are illustrated in the buried soils recorded in the *dhaka* pits, including mottling features from changing redox and water-shaped porosity, discussed above. Whilst groundwater behaviour is influenced by several factors (e.g., aquifers, catchment hydrology, rainfall, land cover and use), here the underlying granite and basalt geology plays a key role in surface and underground

Table 2
Lists and properties of *dhaka* pits recorded during foot surveys along the pediment of the Hill Complex in the ancient core settlement area.

ID	Size m	Depth m	Description
DP1	65 × 20	2	Southern pediment of the Hill Complex. Elliptical depression with thick bush and tree cover on its edges; bottom filled with dark brown very fine sand silty deposit (wetland); no rock fragments visible on surface. The bottom was explored via Trench 1.
DP2	65 × 25	2	Southern pediment of the Hill Complex, c. 100 m W of DP1. Elliptical depression with thick bush and tree cover on its edges, and dry reed vegetation at the center; bottom filled with dark brown very fine silty deposit (wetland).
DP3	45 × 15	1.5	Western pediment of the Hill Complex along the strip-road of Watergate, c. 100 m W of DP 1. Elliptical depression with thick bush and tree cover on its edges, and dry reed vegetation at the center.
DP4	4/1: 50 × 20 4/2: 10×15 4/3: 50×20	1.5 m	Three interconnected pits located on the western pediment of the Hill Complex along the strip-road of Watergate, c. 100 m W of DP1. The four pits are all surrounded by thick bush cover around the edges and dry reed within the depressions. The bottom of 4/4 was explored via Trench 2.
DP5	50×30		Western pediment of the Hill Complex and next to the Watergate. Elliptical depression with thick bush and tree cover on its edges, and dry reed vegetation at the center.

Fig. 5. Water features: Dhaka Pit 1 (left), and Mungwini well (right).

hydrological processes, as reflected in the distribution and variety of water sources observed in the broader landscape. Active springs are found almost invariably at the foot of granitic domes, which afford high water-storage potential. These might have provided essential supply until recently. Data from the southern African region shows high variability in seasonal total rainfall, recurrence of severe droughts and rising temperatures throughout the 1900s (Chikodzi et al. 2013; Farai et al., 2012; Mazvimavi, 2010). This trend is consistent with social memory and photographic and weather records that indicate wetter conditions during the 1800 s (e.g., Chapungu and Nhamo, 2016).

Scattered marshes, swamps, *dambos* (tracts of low-lying, gently sloping, open land that are seasonally waterlogged by seepage from the surrounding high ground; see Bullock, 1992) and soil moisture levels provide further evidence for relatively high water-tables in and around Great Zimbabwe. Oral traditions and written accounts speak about several marshy patches on site, such as around the Chisikana spring and Watergate (Pikirayi et al., 2016; Musindo, 2019;). Crop growing in these swampy areas is mentioned in written records and might have a long

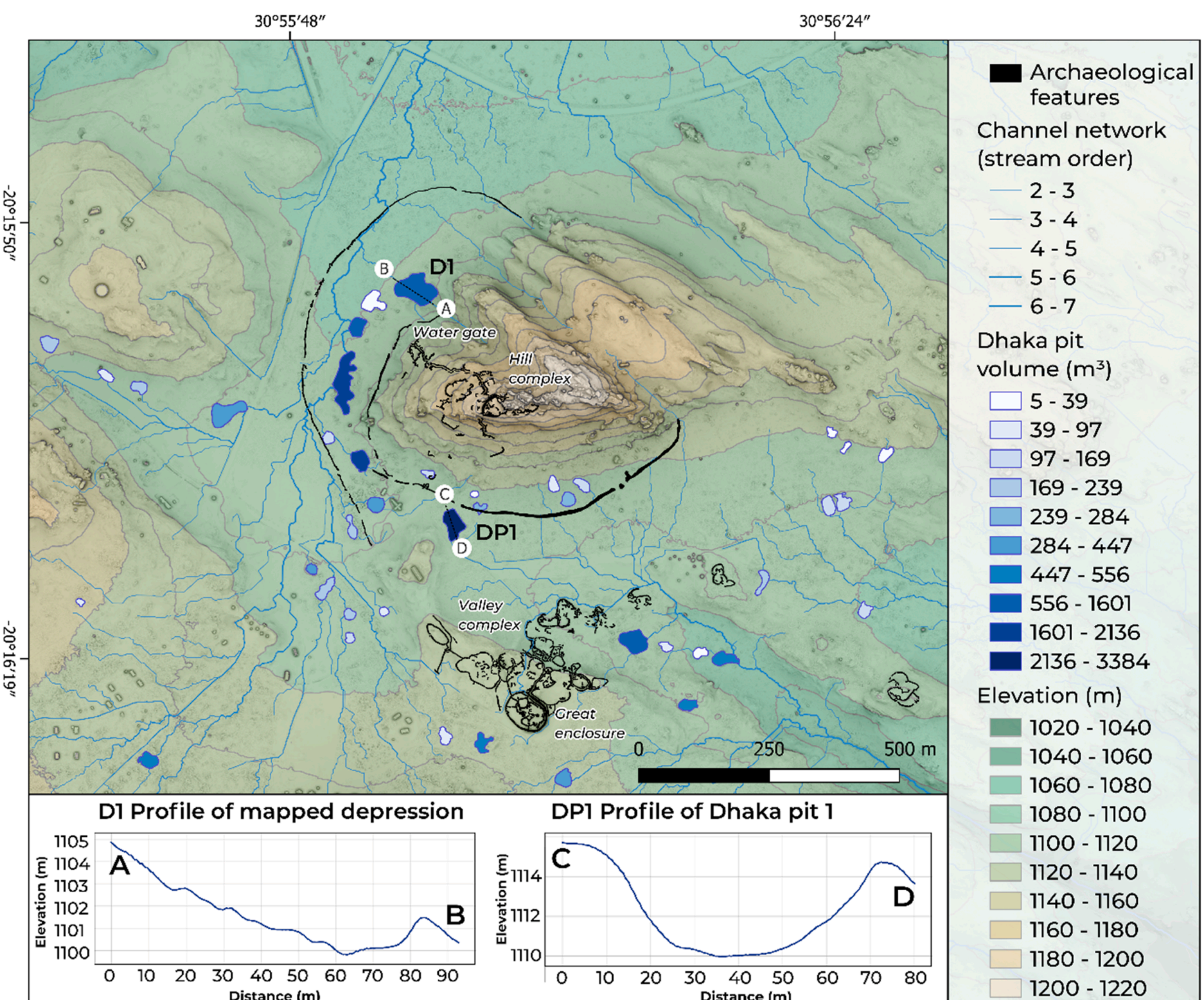

Fig. 6. Great Zimbabwe hydrology showing the depressions and *dhaka* pits (DPs) recorded by the airborne laser scanning (ALS) mapping.

history (Sinclair, 1987). Significantly, most of the plants identified in archaeological assemblages from Great Zimbabwe reflect a riverine habitat (Pikirayi et al., 2016), suggesting the presence of areas with high soil moisture content or groundwater sources.

3.3. Airborne laser scanning (ALS) mapping

Analyses of airborne laser scanning (ALS) data reveal the presence of several closed depressions. Some of these correspond to previously known *dhaka* pits, but the majority have not been mapped before (Fig. 6). While all of them are not necessarily *dhaka* pits, their location and distribution are significant. A number of these have substantial ramparts on the downstream side, which distinguish these features from naturally occurring *dambo* wetlands. Marshes and *dambos* are present today at Great Zimbabwe, and great expanses are found in the surrounding landscape (Pikirayi et al., 2016). In contrast, the steepness and magnitude of the mapped closed depressions with downstream ramparts indicate that these features are of anthropogenic origin. While these might represent deposition of overburden from clay extraction, considerable effort was expended to deposit this material to dam surface water flow and enlarge the depressions.

Comparing these features with the channel network reconstructed from the digital terrain model (DTM), the depressions are located in positions that maximise collection of surface run-off and retain water in the vicinity of the ancient settlement. Estimating the capacity of this system is problematic, as accumulation of sediment and organic matter within the pits leads us to underestimate their volume based on the airborne laser scanning (ALS) data alone. Determining the storage capacity is also difficult as percolation and evapotranspiration are impossible to accurately assess without further in-depth soil sampling and analyses. Despite these caveats, measurements indicate that the total capacity of the system could have reached at least 18,400 m^3. Furthermore, most closed depressions are located within the ancient core area of the site where settlement was most intensive. Careful ground investigation is required to confirm the date and possible anthropogenic origin of these depressions, but their distribution and characteristics suggest extensive management of water at the site.

3.4. Mapping water sources

Mapping of water sources within a 5 km radius of the ancient core settlement area recorded thirteen contemporary springs and associated wells (Fig. 4 and Table 3).

Within the core settlement area, Chisikana spring is located downslope of a granite outcrop, about 220 m to the north-west of the Great Enclosure, and feeds the Chisikana watercourse, which drains the western foot of the Hill Complex. The soil cover consists of a dark, greyish brown fine sand silty loam characterised by rich organic content. Until the 1970s, the area was farmed and used for cattle herding, and the stone fencing present today was built in the 1950s. Under the British Company rule, a prison was located to the south-east of the site complex. Today, the Nemamwa clan continues to use the spring for traditional rituals (Hall, 1905; Fontein, 2006a, 2006b).

The Boroma area, some 5 km south-east of Great Zimbabwe, is characterised by gently sloping to flat open valleys, enclosed by granite outcrops and diverse water sources. At the time of the survey, ponds and marshlands dotted the valley bottoms. Good soil and abundant water allow for small-scale cattle herding and cropping, sustaining about ten farmsteads today. Springs were recorded in most fields and, according to local informants, groundwater can be found at a depth of c. 1 m throughout the year. The predominant soil cover is a dark brown fine sand silty loam, which locals refer to as *chidhaka* and consider ideal soil for farming and pottery making. A perennial spring at the foot of two granite outcrops is said to have been always active even during times of severe droughts, such as that of 1992 (Fig. 7a). Access to water is regulated by the local community, led by the Mutikani and Magogo clans.

South-west of the Hill Complex, two springs feed water to the Muchachari and Heroes Acre areas. The Muchachari spring is found on a flat granite outcrop and feeds two wells: one covered by logs for domestic water supply (Fig. 5b), and an open well for livestock. Less than a kilometre away, another spring runs from the granite area and flows towards the valley bottom at Heroes Acre. Low grass vegetation, granite outcrops and some trees are found close to the spring. According to local informants, this spring is non-perennial and is active until September. Local people make use of perennial springs in the Daitai area, about 3 km south-east of the Hill Complex. Here, three perennial springs are found along the basal domes and several other ones were destroyed by heavy rains in 2013/14, according to local informants.

In the Mungwini area, about 3 km south of the Hill Complex, the main spring is located on gently sloping land in between granite domes. Today, the spring supplies water to about thirty homesteads who employ several conservation measures to manage local water sources (Fig. 7b). These include fencing of land with water rivulets to keep away browsing animals, planting of banana trees to increase soil moisture, and stone fencing of wells and springs to prevent siltation. With rainfall increasingly unpredictable since 2003, damming is now practiced. According to local informants, Mungwini has abundant water and rich wetlands, and it was not devastated by the drought that wrecked other parts of the region in 1947. By contrast, the 1996 drought was more severe: the local well dried out completely and cattle died; and that was followed by considerable rainfall variability. Similar situations had been reported from other regions of southern Zimbabwe (see e.g., Bratton, 1987). At Mungwini, the main well/spring recorded has been used for generations. To conserve water, cattle are not allowed to browse close to water sources and traditional safeguards are in place so that these sources are not contaminated.

Table 3
List and properties of different water sources and water-related features recorded during the foot surveys. Locations were mapped using a geographic positioning system (GPS), and properties were documented with the assistance of local farmers.

Area	*Name*	*Type*	*Coordinates*		*Note*
Core ancient area	Chisikana	Spring	S20°16’19.9’’	E30°55’54.8’’	Sacred spring to the north-west of the Great Enclosure
		Spring	S20°16′10.9″	E30°55′29.0″	Presumed location of a spring west of the Hill Complex
Rondavels		Reservoir	S20°16′16.5″	E30°55′44.7″	Reservoir near the Rondavels to the west of the Hill Complex
		Marsh Point 1	S20°16′17.9″	E30° 55′39.9″	Marshland c. 100 m from the Rondavels reservoir and west of the Hill Complex.
		Marsh Point 2	S20°16′ 17.8″	E30° 55′ 36.3″	Marshland c. 150 m from the Rondavels reservoir
Heroes Acre		Spring	S20°16’34.9’’	E30°55’23.6’’	Spring on a hill opposite to Hill Complex along the road to Morgenster Missionary
Muchachari		Spring	S20°16’59.1’’	E30°55’44.5’’	Two perennial springs along the road to Morgenster Mission
		Well	S20°16’18.3’’	E30°55’12.0’’	Well along the road to Morgenster Mission
Boroma		Spring	S20°17’28.0’’	E30°58’42.8’’	Perennial spring
Daitai		Spring	S20°16′ 47.0″	E30°57′ 05.4″	Perennial spring c. 150 m from the well of Daitai village, south-east of the Hill Complex
		Spring	S20°16′ 40.6″	E30°57′ 00.7″	Non-perennial spring of Daitai village, south-east of the Hill Complex
		Well	S20°16′14.7″	E30°56′08.3″	Well of the Daitai village, south-east of the Hill Complex
Mungwini		Spring and well	S20°17′12.0″	E30°57′26.2″	Perennial spring and well of the Mungwini village, south-east of Hill Complex

Fig. 7. Springs: Boroma area (left) and Mungwini area (right).

4. Discussion

Results from remapping of Great Zimbabwe, albeit preliminary, allow for a consideration of the local landscape palimpsest where *dhaka* pits functioned as water reservoirs. Ethnographic and geoarchaeological surveys, airborne laser scanning (ALS) and hydrological analyses allow a contextualization of the pits within the immediate and broader cultural landscape of Great Zimbabwe. These pits are more numerous than previously known and are found in key hydrological locations. Lying on gently sloping to flat lowland areas formed through a weathering process referred to as etchplanation, these features served as receptacles of water from surrounding hills. At Great Zimbabwe, some of these areas become marshy during the rainy season, favouring the decomposition of surface organic matter and, hence, localised soil development. These locations were exploited for clay extraction to build houses, with the pits subsequently serving as reservoirs of water seeping from the ground as well as runoff from surrounding hills.

The interdisciplinary approach to mapping enabled a reconsideration of Great Zimbabwe's landscape: a granite landscape with a complex geomorphology that required detailed study. Soil sampling surveys proved invaluable to understand past anthropogenic interactions with the landscape. At the base of the Hill Complex, for example, *dhaka* pits preserve a buried dark brown to black, humic silty (peat-like) deposit, whose organic content, vughy porosity and very fine texture relate to standing water and/or prolonged waterlogged conditions. Evidence of changing soil moisture might be associated to water level lowering or drying out. This peat-like material is unique to the *dhaka* pits and likely reflect the capturing of water in the pits.

It has been suggested that high spatial resolution airborne laser scanning (ALS) data is only suitable for detailed studies (e.g., Sadr, 2016). However, at Great Zimbabwe, ALS data enabled mapping of human-environmental interactions at a landscape scale. If, as it is argued here, the extensive water management system at Great Zimbabwe indicates intensive settlement and cultivation, this work could be extended to a regional scale, using evidence of water management as a proxy for detecting other large-scale settlements in the region. Sizable water management structures, such as the *dhaka* pits, are more readily detectable than more subtle features such as cultivation patterns or enclosure walls, and they are less likely to be obscured by dense vegetation or subsequent land use.

Given the urban context of Great Zimbabwe, a city that also experienced climate change for much of its existence, the *dhaka* pits were likely part of an integrated approach towards water conservation not only to meet water supply needs of its population, but also for sustainable agriculture. Water capture and conservation are key to current discussions about the impact of climate change on agricultural production, in particular within the framework of Climate Smart Agriculture (CSA; see Rosenstock et al., 2019; FAO, 2021). CSA is regarded as a pathway towards food security and sustainable development, premised on increasing agricultural throughput, enhancing resilience or adaptation of livelihoods and ecosystems towards climate extremes, and reducing and removing Greenhouse gas emissions. In this framework, water harvesting is a key climate smart practice. In contemporary Africa, small-scale, local communities combine water harvesting with conservation of soil moisture, adapting centuries of traditional water and soil management practices (FAO, 2015, 2016). Whether growing crops or herding cattle, local communities at Great Zimbabwe still manage resources within their landscape by employing climate smart approaches, which show cultural continuity from the distant past.

Though fragmented, the growing body of environmental and archaeological records when integrated with historical and ethnographic information, do paint a new, convincing portrait of Great Zimbabwe: a landscape where human settlement, land and water were intimately linked for a long time and to some extent, continue to do so. Springs and rainwater fed an urban population of ruling elites, religious leaders, craftsmen, and merchants. Water storage facilities were strategically placed to maximise supply and demand. The circular depressions at the base of the Hill Complex could rely on both rain- and groundwater-capture to retain and supply water where and when it was most needed for the burgeoning urban quarters on top, and at the foot of, the hill. The inner and outer perimeter walls (Fig. 6) apparently demarcated some of the largest *dhaka* pits and protected reservoirs from human encroachment. In open areas, springs provided water for household consumption functioning as part of a shared water and land integrated system, like the one supporting some local communities today. Rainwater might also have been harvested by managing slope, fields and cropping patterns for successful crop and livestock farming. Archaeological and historical records, thus, suggest a selective and integrated management of different forms of water resources, tailored to local biophysical properties such as topography, soil and vegetation cover, climate, and socio-cultural requirements—including settlement, spiritual and ritual services. Such a scenario is expression of a flexible and fluid micro-watershed adaptation to endure change in climate, environmental and social conditions. According to Wyatt (2014), micro-watershed adaptation for the Maya coincided with the practicing of raised field agriculture in swampy margins, a farming technique with high productivity (Scarborough, 2003). At Great Zimbabwe, lower areas of micro-watersheds were initially mined for stone and soil for the construction of large-scale political and ritual complexes. As a result, quarry scars were created, with some subsequently converted to water reservoirs. This allowed retention of some of the water flowing towards adjoining streams and rivers, ensuring water availability throughout the year. This partially engineered landscape required maintenance, though organized in a relatively passive manner as runoff was allowed to wash into these basins. Nevertheless, the advent of kingship, an innovative organization or social institution, initiated significant social complexity and precipitated major architectural investments, a condition spreading widely.

A long tradition of scholarship has explored the role of water in the emergence and longevity of past civilisations (Scarborough, 2003). Debates about past water uses have often polarised over the impact of either climate change or human intervention on water availability (e.g., Juuti et al., 2007; Tvedt, 2015; Altaweel and Zhuang, 2018; Sulas and Pikirayi, 2018), especially in the context of southern African past civilizations (Pikirayi, 2006; Huffman, 2008, 2010; Nxumalo, 2019). As the record of past water management increases, it is becoming clear that the role water played in the persistence or decline of past civilisations cannot be reduced to issues of availability and changes to it. Physical forms, ecological functions and cultural values of water all shaped and were shaped by how past societies approached, managed, and conserved water. Several past civilisations emerged and thrived in environments with either highly dynamic or scarce water resources such as the active floodplains of Mesopotamia (e.g., Altaweel, 2018) and the Maya lowlands (e.g., Isendahl et al., 2019) to mention but two different examples. Sub-Saharan Africa is no exception as home to some of the most diverse cultural developments, spanning millennia of social complexity and urbanism intertwined with swings between water excess and scarcity. A prominent example is the emergence of Great Zimbabwe, southern Africa's longest expression of early state formation and urban development, which thrived in a region considered as water deficient in recent times.

In development discourses, sustainable management of African water resources is hampered by natural and human factors: extreme temporal and spatial variability of rainfall and climate, climate change, pollution, deforestation, inappropriate governance, mismanagement and financing (UNECA, 2003; Mutschinski and Coles, 2021). A critical problem with current scholarship on water crises is the limited temporal and spatial frames of examining processes and conditions over the last few decades, often postdating the so-called 'great acceleration' of the 1950s. As shown by recent studies on ecosystem resilience and water sustainability (e.g., Ekblom et al., 2017; Gillson et al., 2021), examining ranges of variability at longer timescales and comparing them to recent ones from the past few decades enables ascertaining whether modern anthropogenic influence is increasing rates of change for ecological indicators beyond their historical range of variability. Addressing variability requires understanding of conditions, processes, and changes across space and over time. The range of variability and human mitigation strategies can inform assessment of management thresholds and corrective action (Gillson et al., 2021). Understanding how humans have modified their environments to conserve and manage water resources throughout time provide valuable insight into the effectiveness of these strategies in response to environmental and societal pressures. Geoarchaeological approaches can examine how these systems developed and evolved over the long duration and across space, exposing resource management strategies that sustained ancient societies throughout. Anthropological approaches add nuance and detail to understanding of how water management systems function directly from people who intimately know and understand the landscapes they inhabit.

In Zimbabwe, water shortages are impacting local communities and environments, creating severe cascading effects on cities and urban sprawls (Remigius and Never, 2010; ZPP, 2019). Since the 1980s, the country has been facing water crises with lack of potable and clean water affecting livelihoods, food production and economic services. The consequences of water shortages include spread of water-borne diseases in cities. In Harare, Zimbabwe's capital city, over 4 million people faced some of the worst cholera outbreaks in 2008, leaving most in water emergency ever since. Recent reviews have questioned the links between climate change and water crises, and called for a consideration of the long and complex history of water politics. In the case of Harare, for example, Musemwa (2021) argues that colonial and postcolonial states failed to secure water supply to the growing urban population, despite the abundance of water in the city's reservoirs. Other studies expose the benefits of local, farmer-led resource management systems, with traditional water practices out-performing formal irrigation systems (e.g., Scoones et al., 2019). Yet, urban growth, climate change and water management have accompanied social development and state formation for over a thousand years, beginning with the emergence of Great Zimbabwe in the early second millennium CE.

5. Conclusion

Based on a combination of foot surveys, remote sensing and mapping of archaeological and hydrological features, this study has generated new data on ancient water management strategies at Great Zimbabwe and its immediate landscape. The findings provide answers to three fundamental questions: (1) how water was managed to sustain ancient urbanization; (2) how water management negotiated a variable climate, and wetter and drier conditions in a region that today is considered as water-scarce; and, (3) how water management contributed to the functioning of Great Zimbabwe's urban landscape. In pursuing these questions, we considered whether past urban landscapes might have operated as integrated, complex ecosystems embedding urban, rural, natural, and cultural dimensions or not. At Great Zimbabwe, an integrated system embedded monumental expressions of power and social complexity, which were integral and operating in mutual relation with the human ecology—the farmers as much as the soils and the water (see e.g., Sinclair et al., 2019). In such a system, understanding the changing cultural landscape context is vital to reconstruct the built environment of Great Zimbabwe.

Geoarchaeological and airborne laser scanning (ALS) mapping revealed the presence of several large, circular depressions within and beyond the core settlement area. Investigations proved that these depressions, locally known as *dhaka* pits, share formalised properties (size, edges, depth), collected water and functioned as sizable reservoirs for the inhabitants of the Hill Complex. ALS detected the presence of such features elsewhere across the site and, significantly, in the surrounding landscapes. Spatial analysis revealed that these features were positioned to maximise the collection and retention of runoff water near settlement areas. The *dhaka r*eservoir system could have afforded a capacity of at least 18,000 m^3 to supply settlement, pastures and crops. Springs and wells would have provided additional sources of water for different purposes. Those recorded in recent surveys include one spring in the core settlement area and several ones scattered across the surrounding landscape, supplying water for human and animal consumption, irrigation and ritual services. Notably, the springs and wells are community managed in the present day.

Taken together, the new records show that physical forms, ecological functions, and cultural values of water all shaped, and were shaped by, how communities approached, managed, and conserved water. Whilst the *dhaka* reservoir system is no longer in use, local communities continue to rely on the management of soil moisture, springs, and wells to meet water needs under changing climatic, environmental, and political conditions. Whilst estimates of water capacity over deep timescales require additional data, new evidence shows a range of variability and mitigation strategies in past and traditional approaches where biophysical factors are as important as cultural and social ones. Since the emergence of Great Zimbabwe over a thousand years ago, this region has endured changing climate, demographic expansion, political struggles and so much more. In returning to the depth and extent of water insecurity across major African cities such as Harare, Great Zimbabwe's legacy offers an opportunity to appreciate the role of biophysical integration, community cohesion and innovation to support settlement over time. Whilst precise dating of the construction and functioning of *dhaka* reservoirs at Great Zimbabwe remains a priority, this study shows the potential of integrating remote sensing, geoarchaeological and ethnographic approaches to examine historical and indigenous water systems to inform climate-smart water management systems.

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Data Availability

Data will be made available on request.

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