To waste or not to waste: A multi-proxy analysis of human-waste interaction and rural waste management in Indus Era Gujarat

Kalyan Sekhar Chakraborty (kalyan.chakraborty@ashoka.edu.in)
Max Planck Institute of Geoanthropology
Shehan Bestel
Independent Researcher
Mary Lucus
Max Planck Institute of Geoanthropology
Patrick Roberts
Max Planck Institute of Geoanthropology
Prabodh Shirvalkar
Deccan College Postgraduate and Research Insititute
Yadubirsingh Rawat
State Department of Archaeology and Museum, India
Thomas Larsen
Max Planck Institute of Geoanthropology
Heather M.-L Miller
University of Toronto

Research Article

Keywords: Indus Valley Civilization, Waste management, Sediment, Phytoliths, Spherulite, Bulk carbona and Nitrogen Isototope

Posted Date: August 9th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3232545/v1

Abstract

Waste management is paramount to town planning and ancient civilizations across the world have spent resources and mobilized labor for waste disposal and reuse. While the Indus Civilization is famous for its urban waste management practices, almost no work has been done on waste management practices at the Indus Era rural settlements. In this paper, using isotopic and microscopic proxies, we characterize the waste that was disposed of at the settlement of Kotada Bhadli to reconstruct the sources of waste, including animal dung, and how rural agro-pastoral settlements in Gujarat during the Indus Era systematically discarded such waste in specific locations. By characterizing waste produced at Kotada Bhadli, we are also able to reconstruct the natural environment and how the natural and cultural landscape around the settlement was exploited by the residents of settlement for their domestic and occupational needs. Our identification of the attention paid to waste disposal by the inhabitants of Kotada Bhadli adds significant data to our understanding of waste disposal as an insight into past lives.

1. Introduction

Critical to understanding human settlement patterns across space and time is the way in which societies have created, defined, managed, and disposed of waste. Indeed, as archaeologists, our work often revolves around discarded objects, rather than their production and usage contexts (Shanks et al., 2004; Sosna & Brunclíková, 2017). Waste encompasses discarded artefacts or portions thereof, food remains, unwanted materials, and detrital materials either lost accidentally or discarded intentionally, or because they are the material leftovers of human actions (Schiffer, 1996). Waste can be disposed of immediately or recycled and reused at different times and possibly by different people. Moreover, what constitutes waste is socially defined and culturally mitigated (Reno, 2014). In this context, archaeological research can shed light on a society's perception of waste, how waste was symbolically constructed (Douglas, 2003), as well as how the materiality of waste was valued (Thompson, 2017), to recycle resources from socio-culturally as well as politically categorized wastes (Alexander & O'Hare, 2020). Archaeological investigation of waste can also help reconstruct human actions (social, cultural and economic), including actors who were involved in the production, processing and the managment of that waste. Waste production is not exclusively a human activity, as it also stems from sources such as the excrements of domesticated animals and the carcases of dead animals.

In this paper, we take a multidisciplinary approach, to explore how wastes were produced, defined, perceived, and disposed of in a rural settlement in the Gujarat region of the Indus Valley or Harappan Civilization of South Asia between the third and second millennium BCE. We first provide the AMS dates to securely place this rural settlement within the Indus Era; then using stable carbon and nitrogen isotopes as well as microscopic remains such as phytoliths and spherulites, we characterize the nature and source of this waste within the settlement of Kotada Bhadli. Within the pan-Indus region, there were numerous rural settlements supporting the Indus economy by providing subsistence goods and raw materials; however, current understanding of Indus rural lifways, especially how the rural inhabitants interacted with their natural and cultural environments, is primarily limited to a basic knowledge of their supposed engagement with agro-pastoralism. This paper therefore aims to discuss the under-studied rural face of the Harappans as manifested in the waste they periodically produced and deliberately discarded.

Comprehending waste disposal is equally as vital as understanding what constitutes waste. By studying how and where wastes were discarded, we can evaluate the efforts and resources mobilized in their disposal within or outside of settlements. Waste disposal often occurs in defined places that are determined by cultural as well as political-economic practices (Alexander & O'Hare, 2020; Rathje & Murphy, 2001). Exploring waste disposal practices in ancient societies allows us to understand past human interaction with space and how meanings were created and attributed to these spaces. Space, an important cultural medium, allows individuals to culturally organize and undertake social, aesthetic, political, and religion or ceremonial practices (Aucoin, 2017). The culture-space relationship is dynamic and can vary both regionally and temporally. The ability to archaeologically investigate the association between waste and waste disposal areas can help in reconstructing the lived experience of a place and the spatial practices within a landscape. Investigating this association at Kotada Bhadli is crucial for evaluating how rural space was assigned, managed and modified during the Indus period and how such practices varied from those in the much more densely populated urban settlements.

2. Waste management during the Indus Era in South Asia

The Indus Valley or the Harappan Civilization was one of the oldest and largest of the world's early urban civilizations, with roots in north-western South Asia from around the fifth millennium BC, and reaching an urban state by the mid-third millennium BC. Archaeological research over the last century has resulted in excavation of numerous settlements identified as cities, towns and villages linked to this civilization (Fig. 1). While there is no evidence of a centralized hierarchical bureaucratic administrative system during the urban period (Green, 2021), a multi-tiered hierarchy of settlement sizes that were engaged in different economic, socio-political, and possibly ritualistic activities is quite evident (Kenoyer, 2000; Mughal, 1990). These different activities produced different kinds of waste across settlements. Based on varied economic conditions and socio-political as well as religious ideologies within these settlements, it is also very likely that waste was identified, managed and removed differently. Despite extensive research, only a few studies have examined how residents from these diverse settlements identified and interacted with wastes produced through continuous occupation and activities within and outside these settlements (Jansen, 1985, 1989, 1993; Kenoyer, 1991; Kharakwal et al., 2012; Shinde et al., 2008; Wright & Garrett, 2017). Organized waste management is paramount for town planning, requiring both labor and resource mobilization, especially for densely populated cities and towns. During the Mature Harappan or Urban Period, significant investments were made in waste management at least for cities and towns; however, our understanding of waste management in smaller rural settlements is lacking. Therefore, it is crucial to investigate waste management, especially when deliberating on disparities in resource availability and utilization by various sizes and types of settlements. Unfortunity, such discussion has largely been neglected for the inherently complex Indus/Harappan Civilization, without a visible centralized ruling system (Green, 2021; Kenoyer, 2000; Possehl, 1998; Wright, 2010).

As stated above, our current understanding of waste management during the Indus Era is primarily restricted to larger Indus centres. By far the most detailed work is Jansen's (1989) discussion of the complex sub-surface, brick-built sanitation and sewage system at Mohenjo-daro, including the use by some households of terracotta pipe drains and closed sewage catchment vessels to collect and transport waste. Similar complex drainage systems can also be observed at other urban centres such as Harappa, Dholavira, Rakhigarhi, Lothal, Kalibangan, etc., where soak pits, which were assumed to have been periodically cleaned by scooping off settled deposits, were also common (Bisht, 2015; Kenoyer, 1991; Lal et al., 2015; Nath, n.d.; Rao, 1979). Wright and Garrett (2018) also argue that some garbage was likely removed from the streets and waste storage pits by wooden carts, the streets were likely swept regularly, water jars regularly filled, and drains and pits scooped out to remove any solid matter.

In contrast, there is a limited understanding as to how various groups residing in other types of Indus settlements, such as small towns and rural settlements, defined waste based on their material and symbolic qualities, distinguished between domestic and industrial wastes, allocated resources for their collection and disposal, and defined space within or outside the settlement as locations where diverse categories of waste were discarded. Kharakwal et al., (2012) and Shinde et al., (2008) have briefly discussed how some of the solid domestic wastes were discarded in their respective excavation reports on Kanmer (a Harappan town) and Farmana (a Harappan village), but this is not common. Our understanding of waste management is even more limited for debris from agro-pastoral economic activities at rural settlements. Scholars have briefly discussed that much of the agricultural waste brought into settlements likely ended up in hearths or served as animal fodder; additionally, some of the animal wastes were recycled as fuel(Chase, Ajithprasad, et al., 2014; Chase et al., 2018, 2020; Lancelotti, 2018; Lancelotti et al., 2017; Reddy, 1994) Biowastes, especially dung, were likely also used as fertilizers for the fields, although no direct evidence exists to support the use of bio-fertilizers by the people of the Indus Era.

Rural settlements may have had fewer resources to develop and maintain the sophisticated waste disposal practiced at large centers. At the same time, they would also have had less need to have sophisticated systems than in the crowded cities and towns. As noted above at the small village site of Farmana in the Ghaggar-Hakra region, garbage pits were identified in which broken pottery along with broken seals and possibly organic refuse were dumped. Solid domestic and occupational waste, such as ash, broken pottery, bones, and craft refuse were additionally found dumped on lanes (Shinde et al., 2008). This sort of dumping was also seen at sites with more formal waste disposal; e.g., at the urban site of Harappa, streets were used as dumping areas for nearby houses during some time periods, while abandoned buildings were also filled with waste prior to the construction of a later phase (Kenoyer, 1991). Similar waste disposal was also observed at the urban site of Rakhigarhi (K.S.C. personal observation). Despite the variety of research conducted, a comprehensive study on what constitutes waste, and how and where it was disposed of, reutilized, and recycled across different types of settlements occupying different regions within the Indus Era remains elusive.

Researchers have long emphasized the existence of regional variation during the Indus period and questioned an overemphasis on Indus homogeneity (Marta, 2013; Miller, 2013; Petrie et al., 2017; Petrie & Lynam, 2020; Possehl, 1998, 2004; Shinde et al., 2008), but primarily with a focus on the larger urban centers. Rural settlements provide additional insights on diversity. While these regional small settlements were economically, technologically and likely also ideologically connected to their nearby urban centres, they were also heavily influenced by the regional geography, climate and contemporary regional Chalcolithic cultures (Chase, 2014; Chase, Meiggs, et al., 2014; Gadekar & Ajithprasad, 2015; Kharakwal et al., 2012; Kuldeep K. Bhan & P. Ajithprasad, n.d.; Lindstrom, 2013; Sonawane et al., 2003). These additional aspects likely impacted their interpretation of waste and cultural definition of potential areas for waste disposal. This paper is focused on detailed identification of waste materials and their disposal patterns at Kotada Bhadli in Gujarat. It is thus not intended to fully cover the diverse rural landscapes of the Indus Civilization and pan-Indus rural waste management, as differences likely existed in the ways waste and space were perceived and constructed by the communities living in various regions.

3. Study area: the settlement of Kotada Bhadli

Kotada Bhadli, located in the Nakhatrana Taluka district of Kachchh in Gujarat, India, was excavated between 2010 and 2013. This excavation unearthed a central residential area with 10 interconnected rooms and a huge stone-built wall surrounding the settlement (Fig. 2) (Shirvalkar & Rawat, 2012). This small settlement, encompassing 3.11 ha, was occupied for a relatively short period of time, as indicated by a comparatively thin layer of occupational debris. The settlement wall surrounding the site is stone-built with a surviving height of approximately 10m, and the approximate maximum width of the wall (including the central pillar) is 8.9m. Excluding the central pillar, the width of the actual wall varies between 3-3.5m. There are no indications that this wall was used as a fortification for military purposes. Rather, it is likely that one of the primary purposes of this wall was to keep the herds inside the settlement, as animal herding was one of the primary economies at this settlement. The wall likely also served to provide a sense of security to the residents of this settlement, and to provide a barrier from natural hazards like floods and storms (Chakraborty, 2019; Chakraborty et al., 2018). While the pupose of this wall is unknown, it was continuously maintained during the occupation at Kotada Bhadli.

Biogenic isotopic analysis of animal dentition and absorbed lipid residue analysis of archaeological vessels suggest that a form of sedentary to semi-sedentary pastoralism, along with domestic level cultivation, was probably the main economy at Kotada Bhadli. Animals were likely raised locally with seasonal movement to nearby grasslands and possibly supplemented with some agricultural leftovers (Chakraborty et al., 2018). Dairy from cattle/water buffalo, and meat from cattle/buffalo, goat, sheep and monogastric animals (such as pig), were likely a major part of their everyday diets, and possibly a source of surplus that tied into a regional interaction network (Chakraborty et al., 2018, 2020). Craft production beyond the household level of non-perishable goods has not been identified at this site. However, the presence of some Harappan-style objects such as Harappan-style beads and other paraphernalia at this settlement indicate that the occupants were probably active consumers of some of the specialized crafts circulating around the wider region. Rather than production and trade in non-perishable craft products, as is frequently suggested for sites in this region, this settlement may have participated in the regional economy by providing nearby settlements with animal products, and animal and human labour. Therefore, it is also possible that this settlement wall served as a checkpoint of control over who entered and exited the settlement.

The ceramic assemblage, architectural pattern, and other household materials used at this settlement indicate its association with the regional Sorath tradition (Shirvalkar & Rawat, 2012). The Sorath tradition is usually thought to be either a regional manifestation of the Indus Civilization in Gujarat, developed by migrants from the Indus alluvial plain (Possehl & Herman, 1987; Possehl & Raval, 1989), or a regional Indus Valley tradition (Shirvalkar, 2013) developed indigenously within the region of Gujarat during the Indus period. While the association between the Sorath and the Harappan tradition is beyond the scope of this article, the economic activities at this settlement suggests its residents were engaged in a local economy focused on a sedentary to semi-sedentary form of pastoralism and household level cultivation, coupled with participation in the larger Indus-dominated economy of the region.

Kotada Bhadli was occupied for a relatively short period of time, as indicated by a comparatively thin layer of occupational debris, varying between 32 and 42 cm. thick in the residential area of the settlement (layer 3). Only this single layer (layer 3) of habitational deposit can be identified in the residential area (Fig. 3, bottom). The other three layers from the residential area include a culturally sterile layer (layer 4) underneath the built structure, a humus layer (layer 1) that contains no cultural remains, and a layer of fallen stones from the stone walls (layer 2) that rests on top of occupational layer 3 (Fig. 3, bottom). In contrast, along the inner face of the southern settlement wall, five layers of occupational deposit can be identified (layers S2, S3, S4, S5 and S7, in Fig. 3 top). As these layers formed due to regular and/or periodic deposition of cultural debris, they potentially formed rapidly during occupation. Out of the five occupational layers along the settlement wall, three layers (layers S3, S5 and S7) contain the maximum amount of ash, whereas layers S2 and S4 are primarily composed of fine sand mixed with ashy materials. The non-occupational layers that can be identified along the inner edge of the southern wall include a layer mixed with ash on which the wall was built (layer S9) and a layer of fallen debris from the wall that formed after the site was abandoned (layer S1) (Fig. 3, top). There are two additional layers (layer S6 and layer S8) with compact sediment without any cultural debris that are found immediately underneath the wall and were probably created as a foundation for the wall. Layer S7 also extends slightly under the wall, between layers S6 and S8. The thickness of each occupational layer along the southern wall varies between 5 and 60 cm; however, there is a natural slope or gradient from the wall towards the centre of the settlement, and therefore all of these layers are slanted and taper downwards from the wall towards the central residential area.

The multi-layer deposits of fine ash mixed with sediments and other cultural debris such as animal bones, broken pottery, and broken pieces of ornaments were found only along both the inner and outer edges of the southern settlement wall (Fig. 3). The heterogeneity of its contents and tapering nature of its spread suggest that these ash layers were formed due to dumping activities. While the ash mixed with cultural debries were found both along the inner and the outer face of the settlement wall, the concentration of these deposits was higher in the inner edge of the wall. As only the southern side of the settlement wall was excavated, it is uncertain whether these ash dumps were only located specifically along the southern settlement wall or whether they were distributed throughout the settlement along the inner side of all four walls. Scatters of these fine ashes mixed with sediment are also visible in residential areas, but were absent inside the multi-room residential structure (Fig. 3 bottom). A lack of structures associated with activities involving fire at this settlement makes it difficult to determine the source of this ashy waste. In certain situations, post-depositional conditions may degrade the firing structures, making them difficult to find during excavations. In addition, it is difficult to identify the more temporary types of firing structures made in semi-permanent camps and small settlements (Lancelotti et al., 2017). Finally, due to the limited excavations undertaken (Fig. 2), we cannot ascertain whether structures associated with activities involving fire are present in the unexcavated area of the settlement, which might have produced considerable amounts of this ash later dumped along the settlement walls. Unfortunately, the complete destruction of the site by agriculture after the final exacavation season prevents further investigation of other areas or additional sampling.

Large quantities of ash dumps are evident in many other Indus period settlements from Gujarat, particularly during the Late Mature Phase of the Indus Civilization (2300 – 1900 BCE), which is marked by an increased use of Sorath-type artefacts (Bisht, 2015; Kharakwal et al., 2012; Shirvalkar & Rawat., n.d.; Uesugi. et al., 2015). Large quantities of fine ash were found from Period 1C of Surkotada (Joshi, 1990), from the Middletown of Dholavira, at Pabumath, and from Period KMR IIB of Kanmer (Kharakwal et al., 2012), as well as at Kotada Bhadli (Shirvalkar & Rawat, n.d., 2012). Kharakwal et al., (2012) posited that such “large dumping of ash” is most likely an indication of vigorous long-term craft activities, and a growing influence by Sorath people that may also have involved periodic conflict. Unfortunately, Kharakwal et al (2012) provide no evidence to substantiate either assertion. Subsequent work by (Lancelotti, 2018), however, confirms that the majority of these fine ashes at Kanmer and at Shikarpur resulted from the burning of animal dung, as well as agricultural byproducts and locally available firewood from different environments, the kinds of fuel one would use for both domestic and industrial purposes. This is a close match with our interpretation of the ash layers from Kotada Bhadli. In order to investigate the characteristics and origins of these ashy layers at Kotada Bhadli, we have undertaken multi-proxy analyses of the ash and sediments, including microscopic and isotopic analyses, as described below.

4. Methods

4.1 AMS dating

Five tiny fragments of charcoal and three animal tooth samples were collected from throughout the settlement of Kotada Bhadli for radiocarbon dating (Fig. 4B). However, due to their small sizes, wood identification of the charcoal samples was not possible. During excavation, the samples were immediately wrapped in aluminum foil after collection, while wearing gloves, and then transferred into plastic vials. Out of these 8 samples, only 4 charcoal samples produced enough carbon for dating (Table

1). Three of those four samples were collected from the area near the southern settlement wall, and one was collected from the residential area (Fig. 4).

Samples were pretreated following the protocol as discussed in (Crann et al., 2017). Samples were processed at the AMS facility at the University of Ottawa. Radiocarbon analyses were performed on a 3MV tandem accelerator mass spectrometer built by High Voltage Engineering (HVE). 12,13,14C + 3 ions were measured at 2.5 MV terminal voltage with Ar stripping. The fraction modern carbon, F14C, is calculated according to Reimer et al. (2004) as the ratio of the sample 14C/12C ratio to the standard 14C/12C ratio (in our case Ox-II) measured in the same data block. Both 14C/12C ratios were background-corrected and the result was corrected for spectrometer and preparation fractionation using the AMS measured 13C/12C ratio and was normalized to δ13C (PDB). Radiocarbon ages were calculated as -8033ln(F14C) and reported in 14C yr BP (BP = AD 1950) as described by (Stuiver & Polach, 1977). The errors on 14C ages (1σ) are based on counting statistics and 14C/12C and 13C/12C variation between data blocks. We do not report δ13C as it is measured on the AMS and contains machine fractionation. Calbriation was performed using OxCal 4.4.2 and the calibrated dates are presented with the 2σ range corresponding to a 95.4% confidence level, and were rounded to nearest 10 years (Table 1 and Fig. 5).

Lab ID	Sample ID	Trench no	Depth below datum (meters)	Layer	Area of the settlement	^{14}C yr. BP	F^{14}C	Calibrated age (BCE) (2σ uncertainty & 95.4% confidence level)
UOC-4155	KTB/CH-2	-XM3	-3.61	S3	Wall	3731±43	0.6285±0.0034	2290 - 1980
UOC-4156	KTB/CH-3	-XJ11	-4.05	S5	Wall	3677±43	0.6327±0.0034	2200-1930
UOC-4157	KTB/CH-4	-XB2	-4.2	3	Residence	3758±43	0.6264±0.0034	2300-2030
UOC- 4158	KTB/CH-5	-XO3	-4.2	S9	Wall	3858±43	0.6186±0.0033	2470-2200

Table 1: Radiocarbon results. Calibration was performed using OxCal v4.4.2 (Ramsey, 2009) and the IntCal20 calibration curve (Reimer et al., 2020). Material codes are described in (Crann et al., 2017).

4.2 Phytolith and Spherulite analysis

Micro-botanical remains and the presence of spherulites were analyzed from twelve sediment samples (Table 2), four of which were collected from the residential area and eight of which were collected from six different layers along the inner face of the southern settlement wall (Table 2, Fig. 4 and Fig. 6). Three of the four samples from the residential area were collected from tentatively-identified floors of three different rooms (within layer 3) while one was collected from the culturally sterile layer below the built structures (layer 4). Preliminary analysis of the phytoliths was carried out at the University of Toronto in

Canada by Chakraborty. The final analysis of the phytolith remains was carried out at Sichuan University in China by Bestel, and the identification of spherulites was carried out at the University of Toronto by Chakraborty.

Sediment samples for phytolith analysis were prepared using standard protocols, e.g., (Rosen et al., 2017) with the heavy liquid sodium polytungstate mixed to a specific gravity of 2.3. No other sample preparation was undertaken to minimize the risk of loss of sample or contamination. The lighter components of the sediments were collected after centrifugation and were mounted in water on slides and partly sealed with nail polish for examination. Slides were scanned at Toronto by Chakraborty under a Cambridge Instruments Galen III microscope using the times 40 objective at a magnification of x400. Final phytolith identifications by Bestel were made based on prior experience with grass, wood and dicotyledon phytoliths, and using a plant reference collection of over 2000 specimens housed at Sichuan University. Phytoliths and other microfossils were identified, including fibres, hairs, and charcoal fragments.

A small amount of sediment from each of twelve sediment samples was sieved using a 200 μm mesh in preparation for fecal spherulite observation. The sediment that passed through the mesh was then poured onto a glass slide and water mounted, then observed using the times 40 objective at Toronto by Chakraborty, as above. Spherulites were identified based on the criteria provided by (Canti, 1998) and (Canti & Brochier, 2017). Counts per slide of individual spherulites were only made to a maximum of 20 for the purpose of this research.

4.3 Carbon and Nitrogen isotope analysis

Sediment samples were first homogenized and treated with 1N HCl to remove inorganic carbonate. Between 5 and 11mg of each sample was analyzed for stable carbon isotopes and between 20 and 25 mg of each sample was analyzed for stable nitrogen isotopes using an Thermo Fisher Elemental Analyzer attached to an Isotope Ratio Mass Spectrometer housed at the Max Planck Institute for Geoanthropology, Jena, Germany.

5 Results

5.1 AMS dates:

The sample (UOC – 4158) producing the oldest date (2470 – 2200 cal BCE) was collected from layer 9 near the southern settlement wall (Table 1, Fig. 3 top and Fig. 4). This layer was formed prior to or contemporary with the building of the settlement wall and lacks any associated cultural material. Since there is no indication of any human occupation prior to the building of the settlement wall, this layer may indicate the beginning of human occupation at the site. The remaining three samples (UOC – 4155, UOC – 4156 and UOC – 4157) that were collected from the occupational layers produced calibrated dates of 2290 – 1980 cal BCE, 2200 – 1930 cal BCE, and 2300 – 2030 cal BCE. These dates fit within the range of the unpublished radiocarbon dates from the same site mentioned in Pokhara et al. (2017), as seen personally by Chakraborty. When modeled using OxCal v4.4.4, it appears that the occupation at the walled settlement began around 2270 BCE and continued till 2000 BCE (68.3% confidence interval), and/or between 2350 BCE and 1810 BCE (95.4% confidence interval) (Fig. 5), that is the Late Mature Phase or the Transitional Phase between Urban and the Post-Urban Period of the Indus Civilization in Gujarat (2300 – 1900 BCE). By the onset of the Late Period of the Indus Civilization (post 1900 BCE), this site was most likely abandoned and was never reoccupied.

5.2 Phytoliths and Spherulites

Of the twelve sediment samples, half produced between 200–300 diagnostic phytoliths per sample, whereas the remainder produced fewer than 50 diagnostic phytoliths (Table 2 and table 3). The majority of the samples with low phytolith counts were collected from the tentative floors of the rooms and from the sterile layers, indicating an environment where phytoliths were not deposited, or deposited in low numbers, and/or were not preserved due to periodic cleaning of floors by the residents of the settlement. Due to fallen debris from the walls being embedded in the floors, the floors could only be tentatively identified, potentially impacting the sample collection. All the ash samples except *Wall _L9* produced high phytolith coutns. A low priority sample *Wall_L1*, although produced high phytolith counts, was collected from the top layer along the settlement wall which formed after the site was abandoned. Non-ash sediment samples from the settlement wall (*Wall_L2*) produced low phytolith counts.

The high counts of *cf.* Asteraceae type phytoliths in some samples reflect the ubiquity of this type of phytolith in the archaeological record, as well as a high degree of fragmentation of these morphotypes, which form extensive, perforated plate structures. For this reason, this morphotype was not included in basic phytolith counts as the fragmentation can skew minimum numbers of individual taxa *(mni)* data for the samples. Occasionally, it is also difficult to separate small fragments of Asteraceae perforated platelets out from thin fragments of charcoal, which is another reason this group was treated separately.

Non-siliceous phytoliths, similar to those found in wood and in tubers, were identified in small numbers (table 3). These phytoliths are not highly diagnostic, making it difficult to interpret whether they are from any particular wood or from tubers. High levels of burning were evident in the tiny wood charcoal at the site and burnt phytoliths are also present in some of the samples, indicating that along with dung and likely burned fodder/agricultural waste, some woods were also part of this ash.

At Kotada Bhadli, the percentage of monocot phytoliths tends to be higher than dicot phytoliths, especially in ash samples with high phytolith counts (table 3). The dicot phytoliths, although very low in number, were distributed throughout the settlement in both ashy and non-ashy layers along the settlement wall and in the residential area (table 3). These dicot phytoliths may relate to the use and discard of furniture, housing materials, food stuffs, and/or woods used for fuel. In contrast, the high counts of monocot phytoliths indicate that the outdoor environment was dominated by grasses, and/or indicate the presence of mats, grass baskets, and grass-based foods or fodders.

A minimum of sixteen distinct plant taxa from varied ecologies were represented by the diverse phytolith morphotypes recovered from the site (table 3). The occurrence of several types of grasses from diverse ecozones in one settlement likely indicates that different habitats were exploited, and the micro-botanical assemblages formed were created via a composite of these diverse habitats. This could be explained by a mosaic or patchwork ecozone community near the site, and human or animal mobility across these ecozones resulting in deposition of such diverse phytoliths.

The majority of the phytoliths encountered at the site are from the stems and leaves of various grasses and are rarely from husks; the later are often indicative of cultivated plants collected for grains (SI Table 1). The exceptions include one phytolith from the husk of a millet-like plant in sample *Wall_L3* and *Wall_L5A* and four phytoliths from the husks of millet-like plants in sample *Wall_L5B*. A single husk phytolith of possible rice was present in Wall_L7B. These make up the only existing evidence of potential crops at the site. A number of possible husk-type phytoliths occurred in *Wall_L5B*, *Wall_L7B* and *Wall_L3* from the ash deposits along the southern settlement wall; however, these were most likely not from crops and may represent the husks of wild grasses.

In contrast, a significant quantity of faecal spherulites (over 20 individual counts), which form in the gut of ruminant herbivorous animals during digestion, are present in almost all the ashy sediment samples from near the southern settlement wall, where large quantities of fine ash were dumped (Table 2 and Fig. 6). These spherulites are completely absent in the sediments from the residential area (*Res_FL-1, Res_FL-2 and Res_FL-3*), and in the layer of fallen debris along the southern settlement wall (*Wall_L1 and Wall_L2*).

5.3 Carbon and Nitrogen Isotope

At Kotada Bhadli, the $\delta^{13}C_{(sed)}$ from the residential area including the pre-occupation layer ranges between − 18.9‰ and − 21.5‰ (mean − 19±1.2‰, n = 4), whereas the $\delta^{13}C_{(sed)}$ for the ashy samples from the settlement wall area, excluding the pre- and post-occupation samples, ranges between − 15.4‰ and − 19.0‰ (mean − 17.3±2.2‰, n = 6) (Fig. 7). The $\delta^{15}N_{(sed)}$ values from the residential area, including the pre-occupational layer, range between 6.7‰ and 9.3‰ (mean 7±1.2‰, n = 4). By contrast, the $\delta^{15}N$ values of ashy wall samples range between 10.4‰ and 17.3‰ (mean 11.1±3.2‰, n = 6). The percentage of total nitrogen and organic carbon as well as the carbon nitrogen ratio also varied between the sediment mixed with ash and sediment without ash. The nitrogen percentage of residential samples, varied between 0.03 to 0.04 (mean 0.03±0.006%, n = 4), whereas for ashy wall samples it varied between 0.01 to 0.11 (mean 0.06±0.033%, n = 6). Similarly, the carbon percentage for the residential samples ranges between 0.41 and 1.52 (mean 0.61±0.50%, n = 4), and for the ashy wall samples, it varied between 0.09 and 1.21 (mean 0.36±0.39%, n = 6). The weight ratio of total organic carbon and nitrogen in residential sediment ranges between 10.6:1 and 36:1, whereas, for ashy wall samples, it varies between 4.1:1 and 16.6:1.

Location	Sample ID	Trench/Room	Location	Area	Ash content	Monocot Phytolith count per slide	Spherulite count per slide
Settlement Wall Area	Wall_L1	XL2	Layer S1	Post-occupational Layer	None	231	0
	Wall_L2	XL2	Layer S2	Occupational layer	Low	8	>20
	Wall_L3	XL2	Layer S3	Occupational layer	High	265	>20
	Wall_L5A	XJ12	Layer S5	Occupational layer	High	298	>20
	Wall_L5B	Xl2	Layer S5	Occupational layer	High	288	<10
	Wall_L7A	XM3	Layer S7	Occupational layer	High	215	<10
	Wall_L7B	XL2	Layer S7	Occupational layer	High	253	>20
	Wall_L9	XL2	Layer S9	Pre-occupational layer	High	22	>20
Residential Area	Res_FL-1	Room 4	Layer 3	Occupational layer	None	8	0
	Res_FL-2	Room 9	Layer 3	Occupational layer	None	8	0
	Res_FL-3	Room 10	Layer 3	Occupational layer	None	3	0
	Res_L4	XB4	Layer 4	Pre-occupational layer	None	2	<5

Table 2: Details of the sediment samples along with their phytolith and spherulite content. Phytoliths were counted between 200 and 300 and spherulites were counted only 20 per slide

Monocot/Dicot	Order	Family	Subfamily	Phytolith types	Wall_L1	Wall_L2	Wall_L3	Wall_L5A	Wall_L5B	Wall_L7A	Wall_L7B	Wall_L9	RES_FL-1	RES_FL-2	RES_FL-3	RES_L4
Monocot	Poales	cf Cyperaceae		cf sedge-bubbly				1		1	1					
Monocot	Poales	Cyperaceae		sedge - small cones						1						
Monocot	Poales	Cyperaceae		sedge hex			3		2		1					
Monocot	Poales	Poaceae /Cyperaceae		long cell	147	2	86	111	70	101	61	22	5	4	3	1
Monocot	Poales	Poaceae /Cyperaceae		bulliform	36	3	64	64	69	69	70		3	2		
Monocot	Poales	Poaceae /Cyperaceae		fan			1			5						
Monocot	Poales	Poaceae /Cyperaceae		blocky reed like					3	5	1					
Monocot	Poales	Poaceae /Cyperaceae		dendritic lc			1	3	12	3	3					
Monocot	Poales	Poaceae /Cyperaceae		dendritic multi					3							
Monocot	Poales	Poaceae /Cyperaceae		lc multi burnt	36	3		7			9					1
Monocot	Poales	Poaceae /Cyperaceae		lc multi - indet	12		42	21	44	7	36					
Monocot	Poales	Poaceae	Aristidoideae	bilobe - aristidoid			1	4	1		2					
Monocot	Poales	Poaceae	Bambusoideae	bamboo cross			2	1		1	2					
Monocot	Poales	Poaceae	Bambusoideae	rondel cf bamboo					2	1	1					
Monocot	Poales	Poaceae	Bambusoideae	squashed saddle				2								
Monocot	Poales	Poaceae	Chloridoideae	saddle small indet			12	34	3	2	11			1		
Monocot	Poales	Poaceae	Ehrhartoideae	bilobe - ehrhartoid						1	1					
Monocot	Poales	Poaceae	Ehrhartoideae	husk rice							1					
Monocot	Poales	Poaceae	Panicoideae	bilobe - panicoid			24	18	12	3	8					
Monocot	Poales	Poaceae	Panicoideae	cross-panicoid					1							
Monocot	Poales	Poaceae	Panicoideae	husk setaria			1	1	4							
Monocot	Poales	Poaceae	Panicoideae/Pooideae	rondel indet			1	1	2	1	5			1		
Monocot	Poales	Poaceae	Bambusoideae/Chloridoideae	saddle long indet				6	1	2	7					
Monocot	Poales	Poaceae	Bambusoideae/Chloridoideae/ Panicoideae	bilobe indet			21	15	14	10	15					
Monocot	Poales	Poaceae	Bambusoideae/Panicoideae	Cross			2	3	1	1	1					
Monocot	Poales	Poaceae	Chloridoideae/Panicoideae	lc multi bilobate			2	4	3		7					
Monocot	Poales	Poaceae		cf husk indet			1		31		3					
Monocot	Poales	Poaceae		grass short cell indet			1	2	10	1	7					
Total Monocot Phytoliths					**231**	**8**	**265**	**298**	**288**	**215**	**253**	**22**	**8**	**8**	**3**	**2**
Dicot	Asterales	Asteraceae		asteraceae perf			12	4		11	25	1	1			
Dicot				dicot	18	2	1		12	3	2	6	2	1		2
Dicot				platy		2	4	3		12	5	5	2	2		2
Dicot				facetted			3					3		1		
Dicot				mc-dicot	57	11	25	7	7	54	9			3	1	14
Dicot				jigsaw						1	1					
Dicot				globular		5			2	4	5					
Total Dicot Phytoliths					**75**	**20**	**45**	**14**	**21**	**81**	**47**	**15**	**5**	**7**	**1**	**18**
Dicot*	cf Asterales	cf Asteraceae		phyto cf. Asteraceae	90		82	58	20	11	500+					
Charcoal				char thick			95		61	122	18		7	2	7	
Charcoal				char indet	123	4	9	200		24	180			3		
cf Wood*				cf. wood multi			18	4	4		6					
cf Wood*				cf. wood single			7	2	11		6					

Table 3: Distribution of phytoliths in the sediments from Kotada Bhadli (* category not included in the final count)

6. Discussion

6.1. Situating Kotada Bhadli within Indus Era Gujarat

The AMS dates from Kotada Bhadli (2350 – 1810 BCE) align with the Late Mature Harappan Phase of Gujarat, corroborated by both the ceramic assemblage and structural remains. These findings are consistent with other Harappan settlements in the Kachchh region of Gujarat such as Periods IIB and III at Kanmer (Goyal et al., 2013; Kharakwal et al., 2012), Period II at Shikarpur (Ajithprasad & Bhan, 2009), Stage VI (1950 – 1800 BCE) at Dholavira (Bisht, 2015), the transitional Phase at Khirsara (2350 – 2150 BCE) (Pokharia et al., 2017), Phase III (2200 – 1900) at Bagasra(Sonawane et al., 2003) and the Sorath phase at Desalpur (thought to be ca. 2100 – 1900 BCE) (Uesugi. et al., 2015). During this Phase, changes in settlement layout have been observed throughout Kachchh. Specifically, at Dholavira the occupation area shrank into the citadel area, and stone structures replaced mud-bricks as building materials; although traditional artifacts from the previous stages of occupation continued at the site, typical Harappan-type steatite seals underwent a stylistic change from square to rectangular (Bisht, 2015). Similar structural changes were also noticed at Kanmer during Period IIB (Kharakwal et al., 2012). The Late Mature Phase in Kachchh is characterized by the dominance of regional pottery styles, known as Sorath-style pottery, alongside Classical Harappan-style pottery. This phase is also identified by the dominance of foundations of structures made by rubble and stones rather than mud or baked-brick, although still following the Classical/Urban Harappan style of cardinal orientation. Thus the chronological dates from Kotada Bhadli also support the existing arguments of an increased utilization of Sorath-type artefacts and building materials in Kachchh around 2300 BCE based on their presence at major Classical Harappan settlements from Kachchh (Ajithprasad & Bhan, 2009; Bisht, 2015; Kharakwal et al., 2012; Lindstrom, 2013).

Other than structural and stylistic changes, discussions of economic shifts during the Late Mature Phase are extremely limited. Economic activities, especially craft production from the previous phase, continued during the Late Mature Phase, and it was only during the end of this phase that extensive craft production ceased to exist in the Harappan settlements in Kachchh. For example, by the end of Phase III (2200 – 1900 BC), Bagasra was no longer a center for craft production; along with a decline in craft production, most of the buildings and the perimeter wall also collapsed during this phase (Lindstrom, 2013). Similar declines in craft production and architectural maintenance were also observed at the site of Shikarpur (Ajithprasad & Bhan, 2009; Chase et al., 2020). At the settlement of Kotada Bhadli, occupied solely during the Late Mature Phase, there is no indication of non-perishable craft manufacturing; however, artefact finds indicate that Harappan-type craft items were entering at this settlement and were utilized by its residents. The residents of Kotada Bhadli were primarily engaged in animal husbandry and likely some form of domestic level cultivation (Chakraborty, 2019; Chakraborty et al., 2018, 2020), similar to the economic activities carried out at other Sorath settlements from the central Saurashtra region in Gujarat

(G. Possehl, 1986; G. L. Possehl, 1992; G. L. Possehl & Herman, 1990; Sonawane, 2000, 2004). There is also the possibility that inhabitants of Kotada Bhadli were engaged in trade in cattle and other animal products for food or labour to other sites, as discussed in (Chakraborty, 2019)

6.2. Identifying waste: Microscopic content of the ash layers

The primary form of waste identified at the settlement of Kotada Bhadli was a huge dump of fine ash mixed with sediments and devoid of large pieces of charcoal, although broken household debris such as pottery and tools, and food residues such as bones were also found. Based on archaeological stratigraphy, this ash was undoubtedly generated during the settlement’s occupation, as suggested by its analyzed contents, including AMS dates. However, due to the absence of structures associated with firing activities, identifying the nature of activities that may have produced such a large quantity of ash requires additional discussion. Interestingly, this ash was not dispersed across the settlement, but was dumped at a very specific location, adjacent to the inner and the outer faces of the settlement wall. This deliberate placement indicates communal descision-making in selecting the dumping area.

The results of phytolith analysis shows that the ash samples had a very high monocot phytolith counts from a variety of plant taxa from different ecologies (table 3, Fig. 6). This result is typical for Gujarat settlements where grasses are dominant (García-Granero et al., 2016b, 2014; Lancelotti, 2018). In addition, the lack of macro-botanical remains and the lack of phytolith morphotypes typical of crop husks at the settlement of Kotada Bhadli may suggest that farming, or at least later stages of grain processing such as threshing, winnowing and pounding(Fuller & Weber, 2005; Reddy, 1997) for human consumption, were probably not carried out inside the walls of Kotada Bhadli. It is therefore unlikely that waste from the processing of cultivated plants were a significant part of the burnt waste that was dumped along the southern settlement wall. This pattern mirrors that of the post-Urban pastoral camp site of Oriyo Timbo, whereReddy, (1994, 1997) concluded that cereal grains were imported to the site rather than produced by the inhabitants. On the contrary, the high count of culm and leaf phytoliths suggests plant parts that are often collected for animal fodder or parts of plants that are generally consumed by grazing animals. As discussed by Lancelotti (2018), animal fodders are generally dominated by culms and leaves, and husks and chaffs are rarely used. The lack of large pieces of charcoal is not surprising given the landscape of Kachchh, which is primarily dominated by grasses and shrubs, seeLancelotti (2018) for a discussion on remains from similar landscpate

Animal dung was considered to be a primary source of fuel at many Harappan sites, especially the smaller ones; however, identifying decomposed and/or burned dung and decomposed agricultural waste can be challenging (Lancelotti, 2018). Along with several other methods (Canti, 1998; Delhon et al., 2008; Evershed & Bethell, 1996; Jones et al., 1988; Lancelotti & Madella, 2012; Peter, 2001; Schelvis, 1992; Valamoti & Charles, 2005), faecal spherulites have been extensively used to detect herbivorous dung in archaeological sediments (Canti, 1998; Canti & Nicosia, 2018; Gur-Arieh et al., 2014). A high count of faecal spherulites in the ash dumps further supports animal dung as a major constituent of waste at this rural agro-pastoral settlement of Kotada Bhadli (Fig. 7). In sum, animal dung burned as fuel, as well as the burning of otherwise unused animal fodder, likely formed the primary waste at the settlement of Kotada Bhadli, and possibly at many other agro-pastoral settlements during the Late Mature Harappan Phase onwards when agro-pastoralism became a major part of the Harappan economy, at least in Gujarat (Bhan, 2011).

6.3. Assessing waste: Stable organic carbon isotope ratios of sediments from Kotada Bhadli

To further assess the waste sources at Kotada Bhadli, we determined bulk organic carbon and nitrogen stable isotope ratios of sediments collected from both the wall dump and residential areas (Fig. 8). Carbon stable isotope ratios of sediment organic carbon can provide insights into past vegetation history, primarily the relative coverage of C_3 and C_4 type vegetation. The global Suess-corrected average $\delta^{13}C$ value of C_3 vegetation is around − 27.1‰ (ranging from − 36‰ to -22‰) and that of C_4 vegetation is around − 12.1‰ (ranging from − 16‰ to -10‰). However, these values vary depending on plant functional type, altitude and mean annual precipitation (Dawson et al., 2002; Hare et al., 2018; Kohn, 2010; G. Wang et al., 2008). A local study from the Godavari plain in the south-central region of the Indian peninsula found that the $\delta^{13}C$ values of C_3 type vegetation in that region vary between − 33.2‰ and − 24.3‰ with a Suess-corrected mean value of -27.7‰ and for C_4 type vegetation vary between − 15.1‰ and − 12.7‰ to with a Suess-corrected mean value of -13.2‰ (Kirkels et al., 2022).

Our findings indicate that Kotada Bhadli had a mixed C_3 and C_4 environment during the occupation period, as indicated by the $\delta^{13}C$ values of soil organic carbon from both the residential (mean − 19±1.2‰) and the ashy wall dump areas (mean − 17.3±2.2‰), with an overall range from − 21.5‰ to -15.4‰ (Fig. 9). These values are similar to those observed at nearby archaeological settlements from Gujarat during the same time period, such as Babar Kot (-21.2‰ to -17.5‰), and Oriyo Timbo from Saurashtra (-22.6‰ to -18.4‰) (Reddy, 1994), and Khirsara in Kachchh (Pokharia et al., 2017), as well as the Holocene sediments from Runn of Kachchh contemporary to the Indus Era (-20.6‰ to 18.2‰) (Ram et al., 2022).

At Kotada Bhadli, interestingly, the ashy sediments from the wall dump area indicate a stronger C_4 influence compared to the residential area. Mixing model using the global values indicate that the percentage of C_4 plants in the residential area including the pre-occupational layer varies between 38% and 53%, whereas for the ashy wall dump layers, it varies between 42% and 79%. Using a more local values from the Godavari plains, a 3% increase of C4 plants for both residential and wall dump area can be observed. However, if we exclude ash layer 9 from the equation (which formed prior to the building of the settlement wall), the percentage of C_4 plants in the wall dump area then ranges between 59–79%. Both the dump and the residential area were contemporary, suggesting that this variation observed at Kotada Bhadli is anthropogenic rather than environmental.

Biogenic isotope data from domesticated animals at the Kotada Bhadli site reveals that cattle and buffalo consumed a diet rich in C_4 plants (Chakraborty et al., 2018). Therefore, if the primary source of the dumped ash is animal dung and unused fodder, it would logically explain the higher C_4 signature in the sediment near the settlement wall. It is also possible that these sediments include the burning of discarded matting made from C_4 vegetation and used for floors, temporary walls and light fencing, as is common in historic and modern times, but this source alone would not explain the high numbers of spherulites in these sediments near the wall, which further point to dung as a major contributor to the waste.

6.4. Organic characterization of waste: Stable nitrogen isotope ratios of sediments from Kotada Bhadli

Nitrogen stable isotope measurements of sediments can also provide further insights into the sources of organic matter; however, interpreting $\delta^{15}N$ values from sediments can be complicated (Riddle et al., 2022; Szpak, 2014a). Animal feces in general are enriched in $\delta^{15}N$ compared to their diet and decomposed feces tend to produce much higher $\delta^{15}N$ values due to a variety of chemical processes during decomposition (Steele & Daniel, 1978; Szpak, 2014b). Therefore, adding animal fertilizer enriches the $\delta^{15}N$ values of plant-soil system (Bol et al., 2005; W. J. Choi et al., 2006; W.-J. Choi et al., 2002; Kriszan et al., 2014; Watzka et al., 2006; Yuan et al., 2012). Animal wastes add mineral nutrients and organic matter to the soil which, in turn, alters the nitrogen isotopic composition of soil (Szpak, 2014a). While there are not many studies that have attempted to identify the presence of dung in archaeological settlements by analyzing sediment $\delta^{15}N$, various studies have demonstrated that animal manure produces a higher $\delta^{15}N$ compared to the endogenous soil (see Szpak, 2014 for detailed discussion). Shahack-Gross et al., (2008), one of the few studies that has attempted to identify the presence of dung in archaeological settlements by analyzing sediment $\delta^{15}N$, found that the sediment from a caprine enclosure produced a $\delta^{15}N$ value between 12.8‰ and 19.7‰ and a cattle enclosure produced a value between 12‰ and 16.3‰

At Kotada Bhadli, the $\delta^{15}N$ from the residential area (Fig. 8), as well as the pre- and post-occupational layers, ranges between 6.7‰ and 9.4‰ (mean 7.8±1.2‰), similar to what is expected from terrestrial soil (Frank et al., 2004; Shahack-Gross et al., 2008). In contrast, the $\delta^{15}N$ values of ash samples from the wall dump area are considerably enriched and range between 10.4‰ and 17.3‰ (mean 12.7±3.2‰), similar to what was observed by(Shahack-Gross et al., 2008) for animal enclosures. This increase of around 5‰ in the $\delta^{15}N$ values in the ashy wall sediments could be linked to the presence of animal dung, which has been shown to increase the $\delta^{15}N$ values of soil significantly (Frank et al., 2004; Lee et al., 2011; Shahack-Gross et al., 2008). Other than animal dung, burning of biomass, especially plant materials can also significantly alter the $\delta^{15}N$ values of the sediment. The $\delta^{15}N$ values will increase immediately after the burning but will soon return to the pre-firing stage(Szpak, 2014a) and, therefore, are unlikely to have influenced the sediments from the wall area with a firing event that took place at least 4000 years ago.

6.5. Percentage and ration of organic elemental carbon and nitrogen in the sediment from Kotada Bhadli

Significant differences in elemental organic carbon and nitrogen composition were observed between the two sediment contexts. The percentage of elemental nitrogen was higher in the wall dump area compared to the residential area, which also affected the C/N ratio. The ashy dump sediments had a considerably lower C/N ratio (mean 8.2 ± 4.6) than the non-ashy sediments (mean 18.6 ± 9.7) (Fig. 8). While burning reduces the organic C and N content due to combustion and volatization, introduction of burned dung and urine to soils may increase nitrogen availability by initially stimulating microbial mineralization of organic carbon. Additional factors, such as elevated soil pH caused by the high content of basic cations in burned dung, may result in higher nitrogen retention relative to carbon. This nitrogen retention is further amplified by a high content of refractory soil organic matter derived from the burned dung (Li et al., 2021; L. Wang et al., 2022). The interplay of these factors helps explain the different C/N ratios observed between the wall dump and residential areas.

7. Conclusion

The ashy sediments from the inner face of this Late Mature Harappan Phase (2300 – 1900 cal. BCE) settlement wall exhibit clear signs of significant disposal of animal dung. These signs include a high content of grass phytoliths, input of C_4 vegetation, higher carbon and nitrogen isotopes values, lower C/N ratio and the presence of dung spherulites in the sediments dumped along the inner (and presumably outer) face of the wall. Along with animal dung, other domestic waste materials such as broken pottery, tools and jewelry, as well as dietary wastes such as animal bones and plant refuse were also deposited in this area. We also infer that unused animal fodder, housing materials such as matting, and broken furniture or other wooden objects were also part of this communal waste.

In a region like Kachchh where Kotada Bhadli is located, wood for fuel was scarce. Therefore, dung was likely used as the primary domestic fuel source. Ash generated from various domestic and/or economic fire-related activities were dumped in specific locations (that is, along the settlement wall), as defined by the community living there. However, soot marks visible on the inner wall face clearly indicate that some waste was also burnt *in-situ*, potentially to get rid of the smell, a practice commonly observed in modern day villages engaged in animal herding. Such efforts further suggesting the nature of interest in maintaining the cleanliness of the settlement by removing waste to the edge of the settlement.

There is little doubt that the huge stone-built settlement wall surrounding Kotada Bhadli was one of the major public architectural feats of this settlement. The construction and maintainence throughout the settlement's occupation required intensive labor and resource investment either centrally facilitated or collaboratively organized. Despite this considerable investment of labour and resources, this particular area seems to have been designated as a dumping ground to dispose of a variety of domestic wastes. While settlement walls are fairly common for Harappan sites in Gujarat, the exact purpose remains unknown. However, due to the sheer size of these walls, it is quite reasonable to argue that the purpose of these walls were beyond simple boundary marking. While it might have been convenient for the residents to dump the waste along the wall, which is at the edge of the settlement; we also speculate that the substantial dumping of domestic waste along the faces of the wall may have bolstered its structure, potentially reducing its regular maintenance costs.

In contrast to the Ash Mounds from the Southern Indian Neolithic (Paddayya, 2019), it is very difficult to determine whether ash production or dumping of the ash within the boundary of Kotada Bhadli served any ritualistic or ceremonial significance. While it is plausible that regular domestic activities and the involvement of the residents in agro-pastoralism were responsible for the production of these occupational and cultural layers, we cannot discount the possibility of ritual and/or ceremonial activities related to this ash debries taking place within this settlement, at either the communal or household level. Some communal/personal ritual/ceremonial activities involving fire and dung may also have contributed to the substantial ash production. It is hard to conclude whether ritualistic origin of this ash warranting special disposal practices that kept the ash within the settlement, rather than dumping primarily outside the wall.

Further, the analysis of occupational waste at the settlement of Kotada Bhadli strengthens our argument that a form of sedentary to semi-sedentary pastoralism was the primary economy (Chakraborty et al., 2018). It seems likely that animals were penned inside the settlement at least partly during the evenings and let to graze during the day times in its vicinity. Alongside herding animals, the residents may have engaged with some household-level cultivation, although due to the lack of direct evidence, it is hard to estimate the extent of plant cultivation at this settlement. The analysis of soil organic carbon further suggests a slightly C_4 dominated but mixed C_3-C_4 environment in this part of Gujarat when the settlement of Kotada Bhadli was occupied, which aligns with the enamel isotopic data of bovines from Kotada Bhadli bovines who were rised locally, suggesting a mixed C_3-C_4 diet, with a slightly higher proportion of C_4 compared to C_3 (Chakraborty et al., 2018).

Using multiple proxies from sediments, we have provided a new perspective on the production, perception, and disposal of waste at an Indus Era rural settlement that was occupied during the Late Mature Phase in Gujarat. The elaborate drainage and waste management system that we observe at many large Harappan settlements were conspicuously absent in this small rural settlement from Gujarat. Instead, we observe an *ad-hoc* basis of waste management, likely managed by individual households but with a specific disposal location at the site agreed upon by the community. This indicates either the lack of nessesary resources for maintaining a centralized waste management system, as adopted by larger settlements, or lack of necessity for such elaborate waste management systems to maintain adequate hygiene. However, it is evident that considerable efforts were made to systematically accumulate and dispose waste in a designated locations to maintain the cleanliness of this settlement.

In this study, we have provided an analysis of how waste was produced and dumped at a much smaller, rural settlements, but also explored how these domestic wastes were perceived and treated by the residents of this settlement. Waste disposal at Kotada Bhadli or any other ancient settlement should not be viewed as a simple disposal of domestic wastes at a specific location. Instead, the complexity involved in its management should be assessed to better understand the continuous interaction between humans, their settlements and the surrounding physical and cultural environment. An acknowledgement of the presence of waste and a discussion on its management in rural settlements provides a rare window into the lives of the inhabitants who were constantly interacting with these ‘unwanted’ materials on a daily basis.

Declarations

Compliance with Ethical Standard:

The authros disclose no conflict of Interest

Funding:

This research has been funded by the University of Toronto and Alexander von Humboldt Doundation

Author Contribution:

Kalyan Sekhar Chakraborty: Conceptualization, sample collection, sample analysis, manuscript preparation

Sheahan Bestel: Phytolith Analysis and manuscript review

Mary Lucus: Analytical support

Thomas Larsen: Analytical support and manuscript review

Partick Roberts: Analytical support and manuscript review

Prabodh Shirvalkar: Excavation, Sample collection and manuscript review

Yadubirsingh Rawat: Excavation, Sample collection and manuscript review

Heather M.-L. Miller: Conceptualization, manuscript preparation and review

Acknowledgement: This study was funded by the University of Toronto and Alexander von Humboldt Foundation. The samples for the analysis were provided by the Archaeological Survey of India and Deccan College Postgraduate and Research Institute. The analysis of the samples used in this study was supported by the Department of Anthropology, University of Toronto and Max Planck Institute for Geoanthropology.

References

1. Ajithprasad, P., & Bhan, K. (2009). *Excavation at Shikarpur: 2008–2009*. https://www.harappa.com/content/excavations-shikarpur-gujarat-2008-2009
2. Alexander, C., & O'Hare, P. (2020). Waste and Its Disguises: Technologies of (Un)Knowing. *Ethnos*. https://doi.org/10.1080/00141844.2020.1796734
3. Aucoin, P. M. (2017). Toward an Anthropological Understanding of Space and Place. In B. B. Janz (Ed.), *Place, Space and Hermeneutics* (pp. 395–412). Springer International Publishing. https://doi.org/10.1007/978-3-319-52214-2_28
4. Bhan, K. K. (2011). Pastoralism in Late Harappan Gujarat, western India: An ethnoarchaeological approach. In T. Psada & A. Uesugi (Eds.), *Occassional Paper 10: Linguistics, Archaeology and the Human Past: Vol. Occassiona* (pp. 1–26). Indus Project: Research Institute for Humanity and Nature.
5. Bisht, R. S. (2015). *Excavations at Dholavira (1989-90 to 2004–2005)*. Archaeological Survey of India.
6. Bol, R., Eriksen, J., Smith, P., Garnett, M. H., Coleman, K., & Christensen, B. T. (2005). The natural abundance of 13C, 15N, 34S and 14C in archived (1923–2000) plant and soil samples from the Askov long-term experiments on animal manure and mineral fertilizer. Rapid Communications in Mass Spectrometry, *19*(22), 3216–3226. https://doi.org/10.1002/rcm.2156
7. Canti, M. G. (1998). The micromorphological identification of faecal spherulites from archaeological and modern materials. Journal of Archaeological Science, *25*(5), 435–444. https://doi.org/10.1006/jasc.1997.0210
8. Canti, M. G., & Brochier, J. É. (2017). Faecal Spherulites. *Archaeological Soil and Sediment Micromorphology*, *Canti 1998*, 51–54. https://doi.org/10.1002/9781118941065.ch5
9. Canti, M. G., & Nicosia, C. (2018). Formation, morphology and interpretation of darkened faecal spherulites. Journal of Archaeological Science, *89*, 32–45. https://doi.org/10.1016/j.jas.2017.11.004
10. Chakraborty, K. S. (2019). *Subsistence-Based Economy and the Regional Interaction Processes of the Indus Civilization Borderland in Kachchh, Gujarat: A Bio-Molecular Perspective*. University of Toronto.
11. Chakraborty, K. S., Chakraborty, S., Le Roux, P., Miller, H. M.-L., Shirvalkar, P., & Rawat, Y. (2018). Enamel isotopic data from the domesticated animals at Kotada Bhadli, Gujarat, reveals specialized animal husbandry during the Indus Civilization. *Journal of Archaeological Science: Reports*, *21*. https://doi.org/10.1016/j.jasrep.2018.06.031
12. Chakraborty, K. S., Slater, G. F., Miller, H. M.-L., Shirvalkar, P., & Rawat, Y. (2020). Compound specific isotope analysis of lipid residues provides the earliest direct evidence of dairy product processing in South Asia. Scientific Reports, *10*(1), 16095. https://doi.org/10.1038/s41598-020-72963-y
13. Chase, B. (2014). On the pastoral economies of Harappan Gujarat: faunal analyses at Shikarpur in context. Heritage: Journal of Multidisciplinary Studies in Archaeology, *2*, 1–22.
14. Chase, B., Ajithprasad, P., Rajesh, S. V., Patel, A., & Sharma, B. (2014). Materializing Harappan identities: unity and diversity in the borderlands of the Indus Civilization. Journal of Anthropological Archaeology, *35*(1), 63–78. https://doi.org/10.1016/j.jaa.2014.04.005

15. Chase, B., Meiggs, D., & Ajithprasad, P. (2020). Pastoralism, climate change, and the transformation of the Indus Civilization in Gujarat: Faunal analyses and biogenic isotopes. *Journal of Anthropological Archaeology*, *59*(December 2019), 101173. https://doi.org/10.1016/j.jaa.2020.101173
16. Chase, B., Meiggs, D., Ajithprasad, P., & Slater, P. A. (2014). Pastoral land-use of the Indus Civilization in Gujarat: faunal analyses and biogenic isotopes at Bagasra. Journal of Archaeological Science, *50*, 1–15. https://doi.org/http://dx.doi.org/10.1016/j.jas.2014.06.013
17. Chase, B., Meiggs, D., Ajithprasad, P., & Slater, P. A. (2018). What is left behind: advancing interpretation of pastoral land-use in Harappan Gujarat using herbivore dung to examine bioshphere strontium isotope (87Sr/86Sr) variation. Journal of Archaeological Science, *92*, 1–12.
18. Choi, W. J., Arshad, M. A., Chang, S. X., & Kim, T. H. (2006). Grain 15N of crops applied with organic and chemical fertilizers in a four-year rotation. Plant and Soil, *284*(1–2), 165–174. https://doi.org/10.1007/s11104-006-0038-8
19. Choi, W.-J., Lee, S.-M., Ro, H.-M., Kim, K.-C., & Yoo, S.-H. (2002). Natural 15 N abundances of maize and soil amended with urea and composted pig manure. In *Plant and Soil* (Vol. 245).
20. Crann, C. A., Murseli, S. M., St-Jean, G., Zhao, X.-L., Clark, I. D., & Kieser, W. E. (2017). First status report on radiocarbon sample preparation techniques at the A.E. Lalonde AMS Laboratory (Ottawa, Canada). Radiocarbon, *59*(3), 695–704.
21. Dawson, T. E., Mambelli, S., Plamboeck, A. H., Templer, P. H., & Tu, K. P. (2002). Stable isotopes in plant ecology. In *Annual Review of Ecology and Systematics* (Vol. 33, pp. 507–559). https://doi.org/10.1146/annurev.ecolsys.33.020602.095451
22. Delhon, C., Martin, L., Argant, J., & Thiébault, S. (2008). Shepherds and plants in the Alps: multi-proxy archaeobotanical analysis of neolithic dung from 'La Grande Rivoire' (Isère, France). Journal of Archaeological Science, *35*(11), 2937–2952. https://doi.org/10.1016/j.jas.2008.06.007
23. Evershed, R. P., & Bethell, P. H. (1996). Application of multimolecular biomarker techniques to the identification of fecal material in archaeological soils and sediments. In *Archaeological Chemistry* (Vol. 625, pp. 13–157). American Chemical Society. https://doi.org/doi:10.1021/bk-1996-0625.ch013
24. Frank, D. A., Evans, R. D., & Tracy, B. F. (2004). *The Role of Ammonia Volatilization in Controlling the Natural 15N Abundance of a Grazed Grassland* (Vol. 68, Issue 2). https://about.jstor.org/terms
25. Fuller, D. Q., & Weber, S. (2005). Formation process and paleoethnobotanical interpretation in South Asia. Journal of Interdisciplinary Studies in History and Archaeology, *2*(1), 93–115.
26. Gadekar, C., & Ajithprasad, P. (2015). A Comparison of Lithic Assemblages Belonging to Economically Diverse Settlements Flourishing During Mid-third Millennium BCE Gujarat. In *Heritage: Journal of Multidisciplinary Studies in Archaeology* (Vol. 3).
27. Goyal, P., Pokharia, A. K., Kharakwal, J. S., Joglekar, P., Rawat, Y. S., & Osada, T. (2013). Subsistence system, paleoecology, and 14C chronology at Kanmer, a Harappan site in Gujarat, India. Radiocarbon, *55*(1), 141–150. https://doi.org/10.2458/azu_js_rc.v55i1.15969

28. Green, A. S. (2021). Killing the Priest-King: Addressing Egalitarianism in the Indus Civilization. Journal of Archaeological Research, *29*(2), 153–202. https://doi.org/10.1007/s10814-020-09147-9
29. Gur-Arieh, S., Shahack-Gross, R., Maeir, A. M., Lehmann, G., Hitchcock, L. A., & Boaretto, E. (2014). The taphonomy and preservation of wood and dung ashes found in archaeological cooking installations: Case studies from Iron Age Israel. Journal of Archaeological Science, *46*(1), 50–67. https://doi.org/10.1016/j.jas.2014.03.011
30. Hare, V. J., Loftus, E., Jeffrey, A., & Ramsey, C. B. (2018). Atmospheric CO2 effect on stable carbon isotope composition of terrestrial fossil archives. Nature Communications, *9*(1). https://doi.org/10.1038/s41467-017-02691-x
31. Jansen, M. (1985). Mohenjo-Daro, city of the Indus Valley. Endeavour, New Series, *9*(4), 161–169.
32. Jansen, M. (1989). Water Supply and Sewage Disposal at Mohenjo-Daro. World Archaeology, *21*(2 Archaeology of Public Health), 177–192.
33. Jansen, M. (1993). *Mohenjo-daro: City of Wells and Drains, Water Splendour 4500 years ago*. Bergish Gladbach Frontinus-Gesellschaft.
34. Jones, A. K. G., Hutchinson, A. R., & Nicholson, C. (1988). The worms of Roman horses and other finds of intestinal parasite eggs from unpromising deposits. Antiquity, *62*(235), 275–276. https://doi.org/10.1017/S0003598X00074007
35. Joshi, J. P. (1990). Excavation at Surkotada 1971-72 and Exploration in Kutch. In *Memoirs of the Archaeological Survey of India* (87th ed.). The Director General Archaeological Survey of India.
36. Kenoyer, J. M. (1991). Urban Process in the Indus Tradition: A Preliminary Mode from Harappa. In R. M. Meadow (Ed.), *Harappa excavations, 1986–1990: a multidisciplinary approach to third millenium urbanism* (pp. 29–60). Prehistory Press.
37. Kenoyer, J. M. (2000). Wealth and socioeconomic hierarchies of the Indus Valley civilization. In Richards Janet & Van Buren Mary (Eds.), *Order, Legitimacy and Wealth in Ancient States* (pp. 88–109). Cambridge University Press.
38. Kharakwal, J. S., Rawat, Y. S., & Osada, T. (2012). *Excavation at Kanmer: 2005-06-2008-09*. Indus Project, Research Institute for Humanity and Nature.
39. Kirkels, F. M. S. A., De Boer, H. J., Concha Hernández, P., Martes, C. R. T., Van Der Meer, M. T. J., Basu, S., Usman, M. O., & Peterse, F. (2022). Carbon isotopic ratios of modern C3 and C4 vegetation on the Indian peninsula and changes along the plant-soil-river continuum - implications for vegetation reconstructions. Biogeosciences, *19*(17), 4107–4127. https://doi.org/10.5194/bg-19-4107-2022
40. Kohn, M. J. (2010). Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and (paleo)climate. PNAS, *107*(46), 19691–19695. https://doi.org/10.1073/pnas.1004933107/-/DCSupplemental
41. Kriszan, M., Schellberg, J., Amelung, W., Gebbing, T., Pötsch, E. M., & Kühbauch, W. (2014). Revealing N management intensity on grassland farms based on natural δ15N abundance. Agriculture, Ecosystems and Environment, *184*, 158–167. https://doi.org/10.1016/j.agee.2013.11.028

42. Kuldeep K. Bhan, & P. Ajithprasad. (n.d.). *Excavation at Shikarpur 2007–2008: A Costal port and craft production center of the Indus Civilization in Kutch, India*.
43. Lal, B. B., Joshi, J. P., Sharma, A. K., Bala, M., & Ramchandran, K. S. (2015). *Excavations at Kalibangan: The Harappans (1960-69)*.
44. Lancelotti, C. (2018). ' Not all that burns is wood '. A social perspective on fuel exploitation and use during the Indus urban period (2600 – 1900 BC). PLoS One, *13*(3), e0192364.
45. Lancelotti, C., & Madella, M. (2012). The 'invisible' product: Developing markers for identifying dung in archaeological contexts. Journal of Archaeological Science, *39*(4), 953–963. https://doi.org/10.1016/j.jas.2011.11.007
46. Lancelotti, C., Ruiz-Pérez, J., & García-Granero, J. J. (2017). Investigating fuel and fireplaces with a combination of phytoliths and multi-element analysis; an ethnographic experiment. Vegetation History and Archaeobotany, *26*(1), 75–83. https://doi.org/10.1007/s00334-016-0574-y
47. Lee, C., Hristov, A. N., Cassidy, T., & Heyler, K. (2011). Nitrogen isotope fractionation and origin of ammonia nitrogen volatilized from cattle manure in simulated storage. Atmosphere, *2*(3), 256–270. https://doi.org/10.3390/atmos2030256
48. Li, J., Pei, J., Liu, J., Wu, J., Li, B., Fang, C., & Nie, M. (2021). Spatiotemporal variability of fire effects on soil carbon and nitrogen: A global meta-analysis. Global Change Biology, *27*(17), 4196–4206. https://doi.org/10.1111/gcb.15742
49. Lindstrom, K. E. (2013). *Pottery preferences and community dynamics in the Indus Civilization borderland*. University of Wisconsin-Madison.
50. Marta, A. (2013). Regional Variation in the Indus World: The diversity with the seals. In Abraham Shinu Anna, Gujjapalli Praveena, Raczek Teresa P., & Rizvi Uzma Z (Eds.), *Connections and Complexity: New Approaches to the Archaeology of South Asia* (pp. 341–354). Left Coast Press Inc.
51. Miller, H. M.-L. (2013). Weighty Matters: Evidence for Unity and Regional Diversity from the Indus Civilization Weights. In S. A. Abraham, P. Gullapalli, T. P. Raczek, & U. Z. Rizvi (Eds.), *Connections and Complexity: New Approaches to the Archaeology of South Asia* (pp. 161–176). Left Coast Press.
52. Mughal, D. M. R. (1990). Further Evidence of the Early Harappan Culture in the Greater Indus Valley: 1971-90. South Asian Studies, *6*, 175–199.
53. Nath, A. (n.d.). *Excavations at Rakhigarhi (1997-98 to 1999–2000)*.
54. Paddayya, K. (2019). Neolithic Ashmounds of the Deccan, India: A Posthumanist Perspective. Archaeological Review from Cambridge, *34*(2), 44–64.
55. Peter, B. (2001). Vetrified dung in archaeological contexts: an experimental study on the process of its formation in the Mosu and Bobirwa areas. Pula:Botswana Journal of African Studies, *15*(1), 125–143.
56. Petrie, C. A., & Lynam, F. (2020). Revisiting Settlement Contemporaneity and Exploring Stability and Instability: Case Studies from the Indus Civilization. Journal of Field Archaeology, *45*(1), 1–15. https://doi.org/10.1080/00934690.2019.1664848

57. Petrie, C. A., Singh, R. N., Bates, J., Dixit, Y., French, C. A. I., Hodell, D. A., Jones, P. J., Lancelotti, C., Lynam, F., Neogi, S., Pandey, A. K., Parikh, D., Pawar, V., Redhouse, D. I., & Singh, D. P. (2017). Adaptation to variable environments, resilience to climate change: investigating land, water and settlement in Indus Northwest India. Current Anthropology, *58*(1), 1–30. https://doi.org/10.1086/690112
58. Pokharia, A. K., Agnihotri, R., Sharma, S., Bajpai, S., Nath, J., Kumaran, R. N., & Negi, B. C. (2017). Altered cropping pattern and cultural continuation with declined prosperity following abrupt and extreme arid event at ~ 4,200 yrs BP: Evidence from an Indus archaeological site Khirsara, Gujarat, western India. PLoS ONE, *12*(10), 1–17. https://doi.org/10.1371/journal.pone.0185684
59. Possehl, G. (1986). African Millets in South Asian Prehistory. In J. Jacobson (Ed.), *Studies in the Archaeology of India and Pakistan*. Oxford and IBH publishing co.
60. Possehl, G. (1998). Sociocultural complexity without state: The Indus Civilization. In M. G. Feinman & J. Marcus (Eds.), *Archaic States* (pp. 261–291). School of American Research Press.
61. Possehl, G. (2004). Rojdi: A Sorath Harappan Settlement in Saurashtra. Marg, *55*(3), 80–88.
62. Possehl, G. L. (1992). The Harappan Civilization in Gujarat: The Sorath and Sindhi Harappans. The Eastern Anthropologist, *45*(1–2), 117–154.
63. Possehl, G. L., & Herman, C. F. (1987). The Sorath Harappan: A new regional manifestation of the Indus Urban Phase. In M. Taddei & P. Callieri (Eds.), *Ninth International Conferecen of the Association of South Asian Archaeologists in Western Europe* (pp. 295–319). Istituto Italiano Per IL Medio Ed Estremo Oriente.
64. Possehl, G. L., & Herman, C. F. (1990). The Sorath Harappan: A new regional manifestation of the Indus Urban Phase. In M. T. with assistance of P. Callieri (Ed.), *Ninth International conference of the Association of South Asian Archaeologists in Western Europe: Vol. South Asia* (pp. 295–319). Istituto Italiano Per IL Medio Ed Estremo Oriente.
65. Possehl, G. L., & Raval, M. H. (1989). *Harappan Civilization and Rojdi*. Oxford and IBH New Delhi.
66. Ram, F., Thakkar, M., Chauhan, G., Bhusan, R., Juyal, N., & Sarkar, A. (2022). Carbon isotope and organic geochemistry of the Holocene sediments from Rann of Kachchh: implications to the preservation of organic matter and climate during the Indus Valley Civilisation. *EGU General Assembly, Vienna, Austria*. https://doi.org/10.5194/egusphere-egu22-555
67. Ramsey, C. B. (2009). Dealing with outliers and offsets in radiocarbon dating. Radiocarbon, *51*(3), 1023–1045. https://doi.org/10.1017/s0033822200034093
68. Rao, S. R. (1979). *Lothal: A Harappan Port Town*. The Director General Archaeological Survey of India.
69. Rathje, W. L., & Murphy, C. (2001). *Rubbish!: The Archaeology of Garbage*. The University of Arizona Press.
70. Reddy, S. N. (1994). Plant Usage and Subsistance Modeling: An Ethnoarchaeological Approach to the Late Harappan of Northwest India. In *Department of Antrhopology: Vol. Doctor of*. University of Wisconsin-Madison.

71. Reddy, S. N. (1997). If the threshing floor could talk: Integration of agriculture and pastoralism during the late Harappan in Gujarat, India. Journal of Anthropological Archaeology, *16*(2), 162–187. https://doi.org/10.1006/jaar.1997.0308
72. Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Hajdas, I., Heaton, T. J., Hogg, A. G., Hughen, K. A., Kromer, B., Manning, S. W., Muscheler, R., … Talamo, S. (2020). The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon, *62*(4), 725–757. https://doi.org/10.1017/RDC.2020.41
73. Reno, J. O. (2014). Toward a New Theory of Waste: From 'Matter out of Place' to Signs of Life. Theory, Culture & Society, *31*(6), 3–27.
74. Riddle, B., Fox, J., Mahoney, D. T., Ford, W., Wang, Y. T., Pollock, E., & Backus, J. (2022). Considerations on the use of carbon and nitrogen isotopic ratios for sediment fingerprinting. *Science of the Total Environment*, *817*. https://doi.org/10.1016/j.scitotenv.2021.152640
75. Rosen, A., Macphail, R., Liu, L., Chen, X., & Weisskopf, A. (2017). Rising social complexity, agricultural intensification, and the earliest rice paddies on the Loess Plateau of northern China. Quaternary International, *437*, 50–59. https://doi.org/10.1016/j.quaint.2015.10.013
76. Schelvis, J. (1992). The identification of archaeological dung deposits on the basis of remains of predatory mites (Acari; Gamasida). Journal of Archaeological Science, *19*(6), 677–682. https://doi.org/10.1016/0305-4403(92)90037-4
77. Schiffer, M. B. (1996). *Formation processes of the archaeological record*. University of Utah Press.
78. Shahack-Gross, R., Simons, A., & Ambrose, S. H. (2008). Identification of pastoral sites using stable nitrogen and carbon isotopes from bulk sediment samples: a case study in modern and archaeological pastoral settlements in Kenya. Journal of Archaeological Science, *35*(4), 983–990. https://doi.org/10.1016/j.jas.2007.07.002
79. Shanks, M., Plat, D., & Rathje, W. L. (2004). The perfume of garbage: Modernity and the archaeological. Modernism/Modernity, *11*(1), 61–83.
80. Shinde, V., Osada, T., Uesugi, A., & Kumar, M. (2008). A Report on Excavation at Farmana 2007-08. In Osada Toshiki & Uesugi Akinori (Eds.), *Occasional Paper 6: Linguistics, Archaeology and the Human Past*. Indus Project: Research Institute for Humanity and Nature.
81. Shirvalkar, P. (2013). Harappan migration: A perspective about the Gujarat Harappans. Heritage: Journal of Multidisciplinary Studies in Archaeology, *1*, 301–318.
82. Shirvalkar, P., & Rawat, Y. (n.d.). Stratigraphy. In P. Shirvalkar & Y. Rawat (Eds.), *Excavation at Kotada Bhadli, Taluka: Nakhatrana, District: Kachchh, Gujarat (2010–2014)* (pp. 39–47). Archaeological Survey of India.
83. Shirvalkar, P., & Rawat., Y. S. (n.d.). *Excavation at Kotada Bhadli, Taluka: Nakhatrana, District: Kachchh, Gujarat (2010–2014)* (P. Shirvalkar & Y. S. Rawat, Eds.). Archaeological Survey of India.
84. Shirvalkar, P., & Rawat, Y. S. (2012). Excavation at Kotada Bhadli, District Kachchh, Gujarat: A perliminary report. Puratattva, *42*, 182–201.

85. Sonawane, V. H. (2000). Early Farming Communities of Gujarat, India. In B. Peter, B. Doreen, B. David, B. Dee, S. Vasant, S. Richard, & S. Glenn (Eds.), *Indo-Pacific Prehistory: the Melaka papers, 16th Congress of the Indo-Pacific Prehistory Association* (pp. 137–146). Indo-Pacific Prehistory Assiciation, Canberra: Australian National University.
86. Sonawane, V. H. (2004). Harappan Civilization in Western India with special reference to Gujarat. Journal of Interdisciplinary Studies in History and Archaeology, *1*(2), 63–78.
87. Sonawane, V. H., Ajithprasad, P., Bhan, K. K., Krishnan, K., Prathapachandran, S., Majumdar, A., Patel, A. K., & Menon, J. (2003). Excavation at Bagasra- 1996–2003: A Preliminary Report. Man and Environment, *28*(2), 21–50.
88. Sosna, D., & Brunclíková, L. (2017). Introduction. In D. Sosna & L. Brunclíková (Eds.), *Archaeologies of waste* (1st ed., pp. 1–14). Oxbow Books. http://www.jstor.org.myaccess.library.utoronto.ca/stable/j.ctt1kw2bcw.7
89. Steele, K. W., & Daniel, R. M. (1978). Fractionation of nitrogen isotopes by animals: A further complication to the use of variations in the natural abundance of 15N for tracer studies. The Journal of Agricultural Science, *90*(1), 7–9. https://doi.org/10.1017/S002185960004853X
90. Stuiver, M., & Polach, H. A. (1977). Discussion Reporting of 14 C Data. Radiocarbon, *19*(3), 355–363. https://doi.org/10.1017/s0033822200003672
91. Szpak, P. (2014a). Complexities of nitrogen isotope biogeochemistry in plant-soil systems: Implications for the study of ancient agricultural and animal management practices. In *Frontiers in Plant Science* (Vol. 5, Issue JUN). Frontiers Research Foundation. https://doi.org/10.3389/fpls.2014.00288
92. Szpak, P. (2014b). Complexities of nitrogen isotope biogeochemistry in plant-soil systems: Implications for the study of ancient agricultural and animal management practices. In *Frontiers in Plant Science* (Vol. 5, Issue JUN). Frontiers Research Foundation. https://doi.org/10.3389/fpls.2014.00288
93. Thompson, M. (2017). *The Creation and Destruction of Value - New Edition*. Pluto Press. https://doi.org/10.2307/j.ctt1rfsn94
94. Uesugi., A., Rajesh, S. V., Abhayan, G. S., Chase., B., Rawat., Y. S., Patel., A., Kumar., A., & Gadekar., C. (2015). Indus Ceramics from Desalpur, Kachchh Gujarat. *Heritage: Journal of Multidisciplinary Studies in Archaeology*, *3*, 180–218.
95. Valamoti, S. M., & Charles, M. (2005). Distinguishing food from fodder through the study of charred plant remains: an experimental approach to dung-derived chaff. Vegetation History and Archaeobotany, *14*(4), 528–533. https://doi.org/10.1007/s00334-005-0090-y
96. Wang, G., Feng, X., Han, J., Zhou, L., Tan, W., & Su, F. (2008). Paleovegetation reconstruction using δ 13 C of Soil Organic Matter. In *Biogeosciences* (Vol. 5).
97. Wang, L., Xu, H., Zhang, H., & Zhang, Y. (2022). Grazing and Mowing Affect the Carbon-to-Nitrogen Ratio of Plants by Changing the Soil Available Nitrogen Content and Soil Moisture on the Meadow Steppe, China. Plants, *11*(3). https://doi.org/10.3390/plants11030286

98. Watzka, M., Buchgraber, K., & Wanek, W. (2006). Natural 15N abundance of plants and soils under different management practices in a montane grassland. Soil Biology and Biochemistry, *38*(7), 1564–1576. https://doi.org/10.1016/j.soilbio.2005.11.007
99. Wright, R. P. (2010). *The ancient Indus: urbanism, economy, and society*. Cambridge University Press.
100. Wright, R. P., & Garrett, Z. S. (2017). Engineering Feats and Consequences: Workers in the Night and the Indus Civilization. In *Archaeology of the Night: Life After Dark in the Ancient World* (pp. 287–306). University Press of Colorado. https://doi.org/10.5876/9781607326786.c014
101. Yuan, Y., Zhao, M., Zhang, Z., Chen, T., Yang, G., & Wang, Q. (2012). Effect of different fertilizers on nitrogen isotope composition and nitrate content of brassica campestris. Journal of Agricultural and Food Chemistry, *60*(6), 1456–1460. https://doi.org/10.1021/jf203105t

Figures

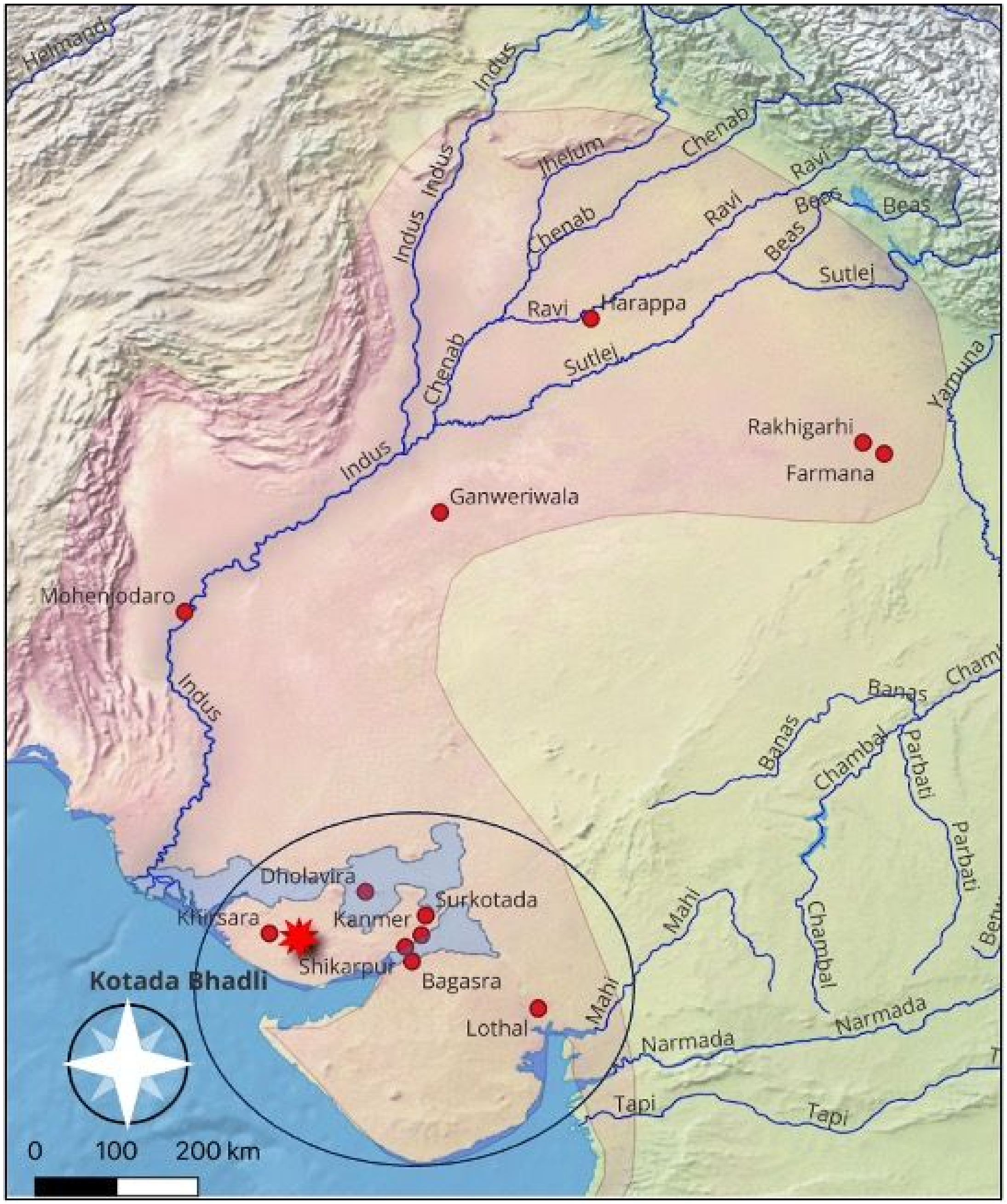

Figure 1

Distribution of sites mentioned in the text, the shaded area showing the approximate extent of Mature Harappan Period sites, and the circled area indicating the extent of the Gujarat state.

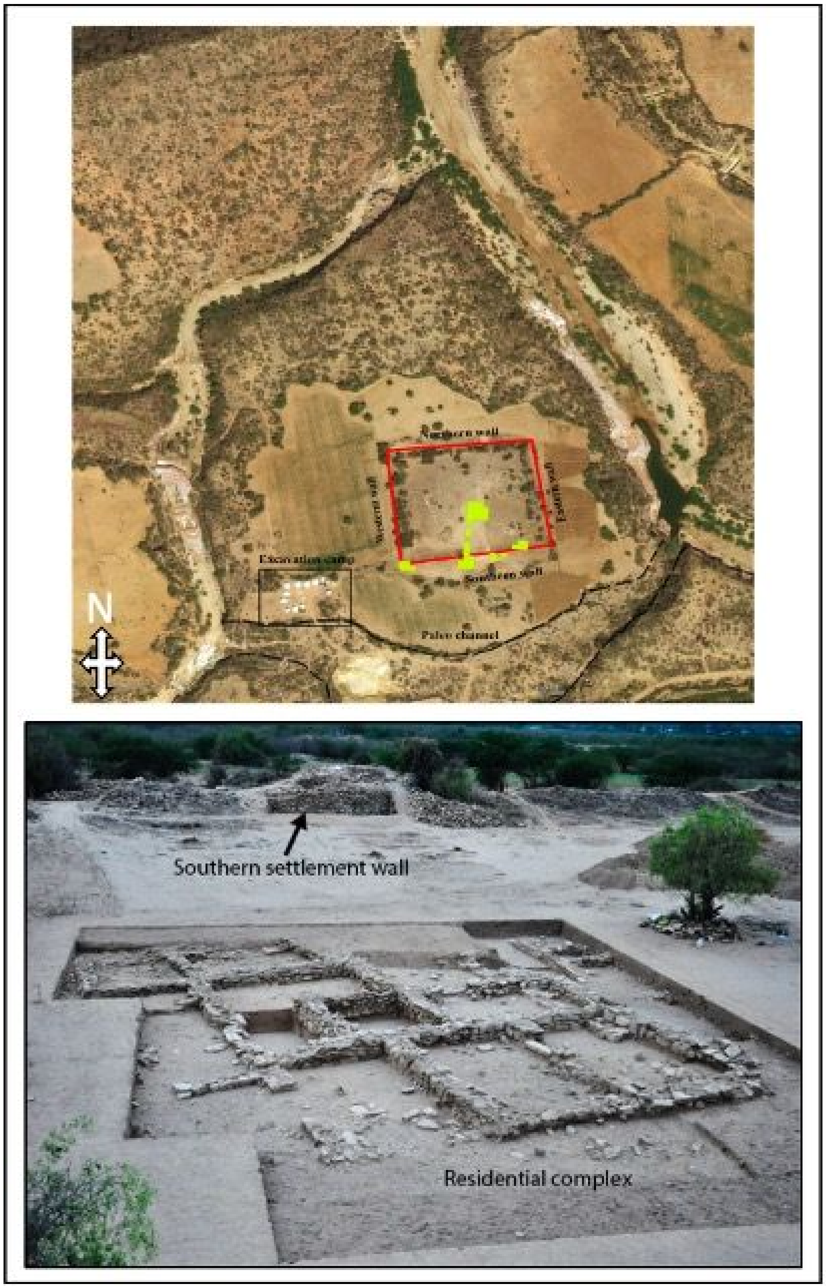

Figure 2

Google Earth image (top) of the settlement of Kotada Bhadli from 2012, showing its location, the settlement wall and the extent of excavation. The bottom photo taken from north facing sounth shows the inner face of the southern settlement wall with the central residential structure with interconnected rooms in the foreground.

Figure 3

Layers along the inner edge as well as underneath the settlement wall showing high concentration of fine ash and the dumping of occupational debris (top), and layers from inside of the multi-room residential structure which are devoid of ash (bottom).

Figure 4

(A) Schematic diagram of the residential area with interconnected rooms, and the location of sediment and charcoal samples collected from the residential area. Grids in 5 meters. (B) Trench map of the settlement of Kotada Bhadli; maroon 5m^2 boxes indicate excavation blocks, yellow boxes indicate the sampling location for charcoal samples for AMS dating and blue boxes indicate the location of sediment samples for phytoliths and spherulites.

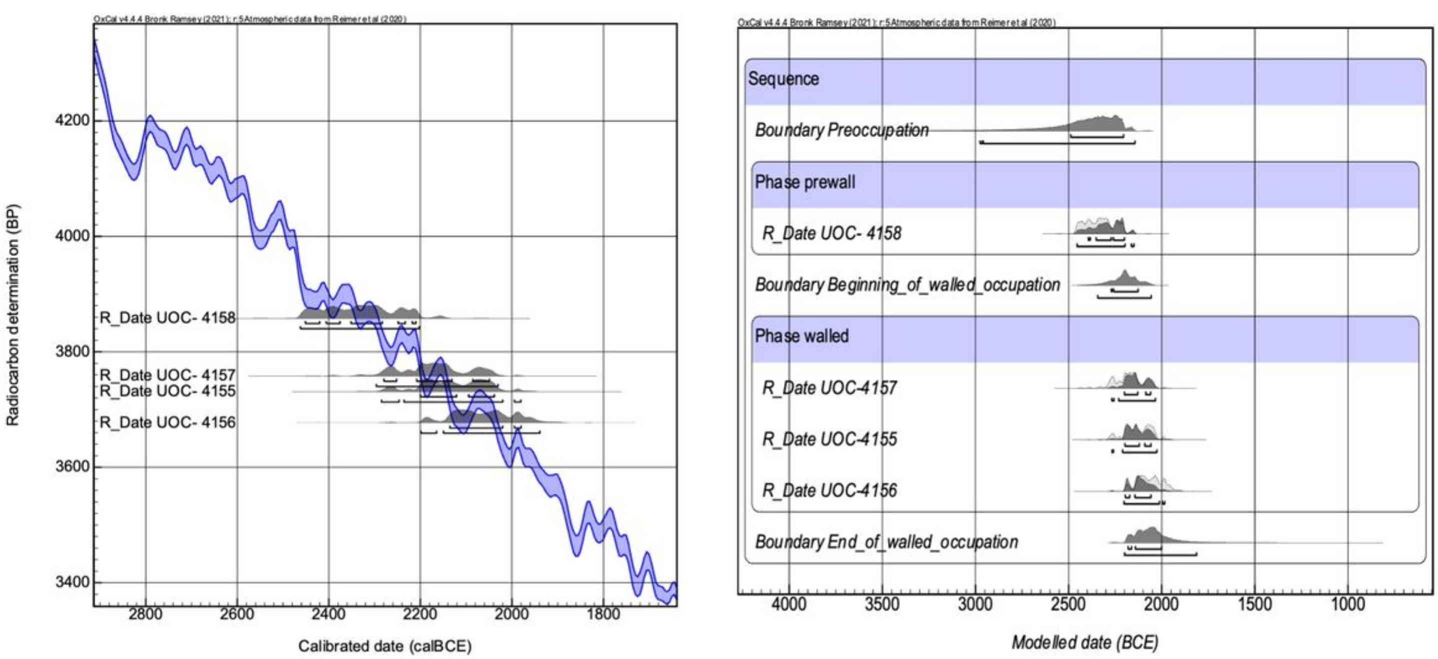

Figure 5

Modeled calibrated ages of charcoal samples from Kotada Bhadli produced using OxCal v4.4.4 (Ramsey, 2009) and the IntCal20 calibration curve (Reimer et al., 2020).

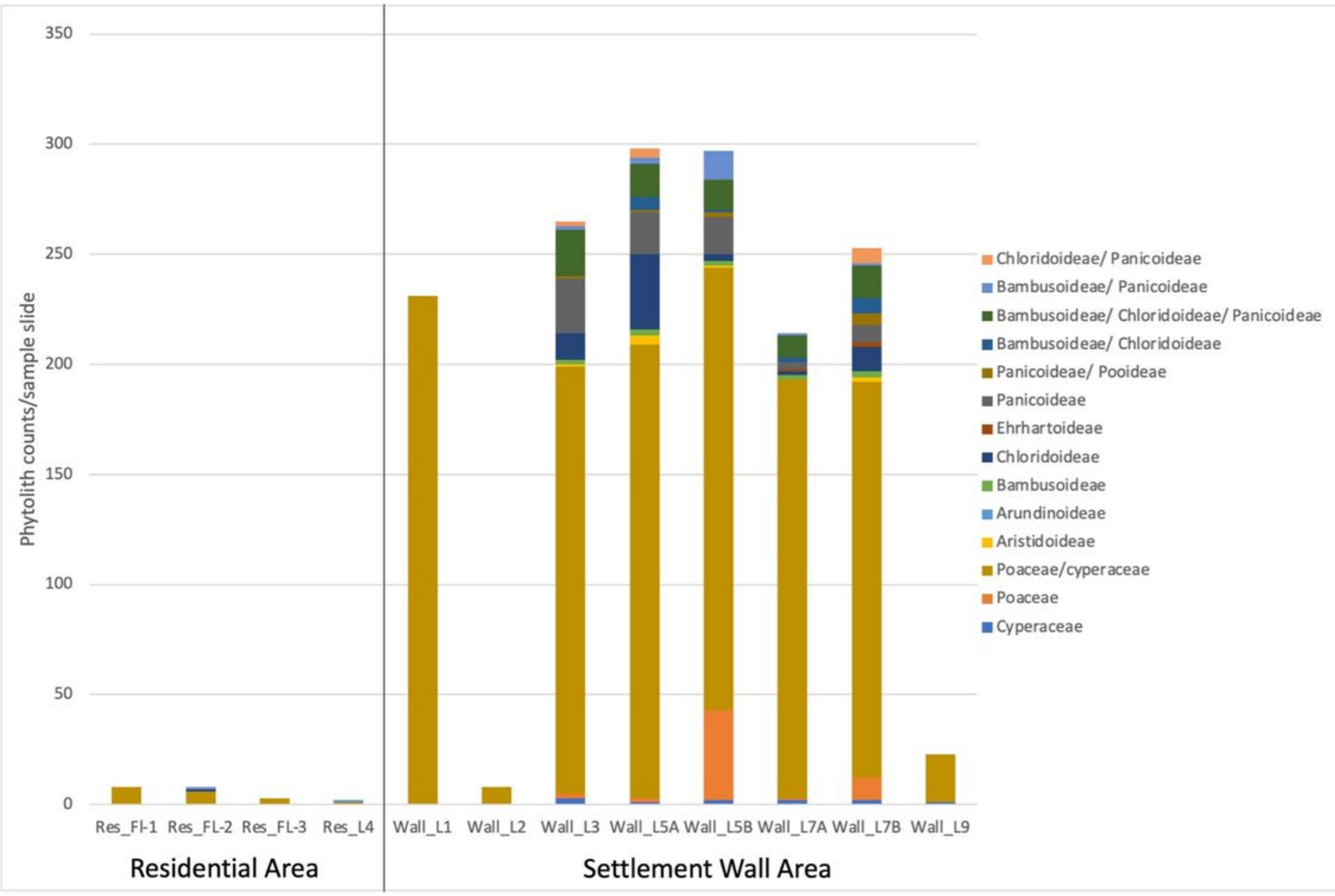

Figure 6

Distribution of identified monocot phytoliths at the settlement of Kotada Bhadli, not including dicot, *cf.* wood and *cf.*Asteraceae type phytoliths

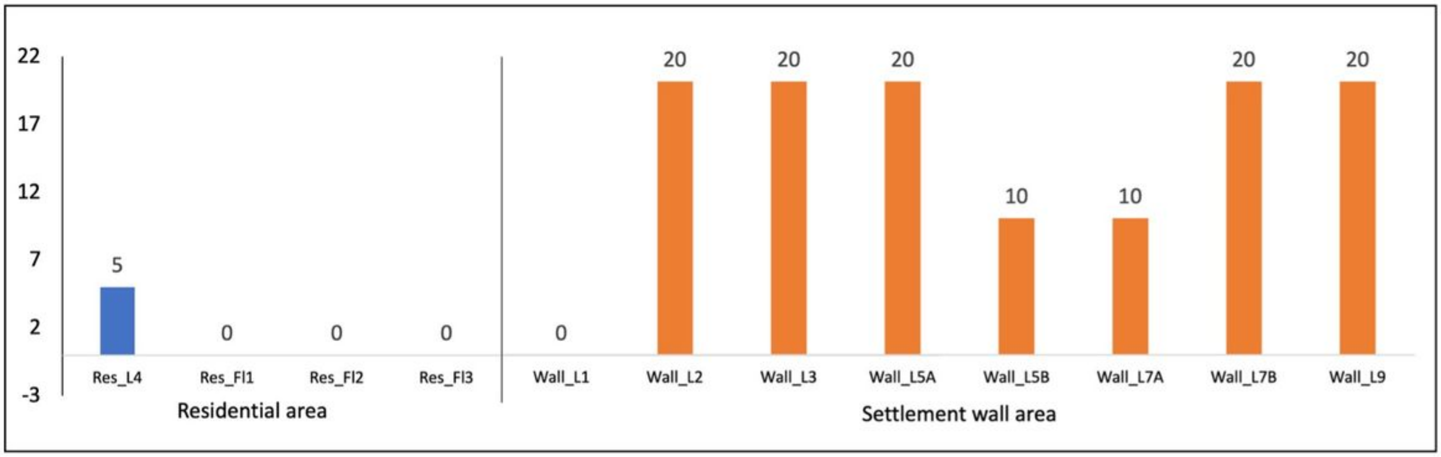

Figure 7

Spherulite counts in the sediments from the residential area and in the dump area along the inner face of the settlement wall at Kotada Bhadli (counts were stopped at 20).

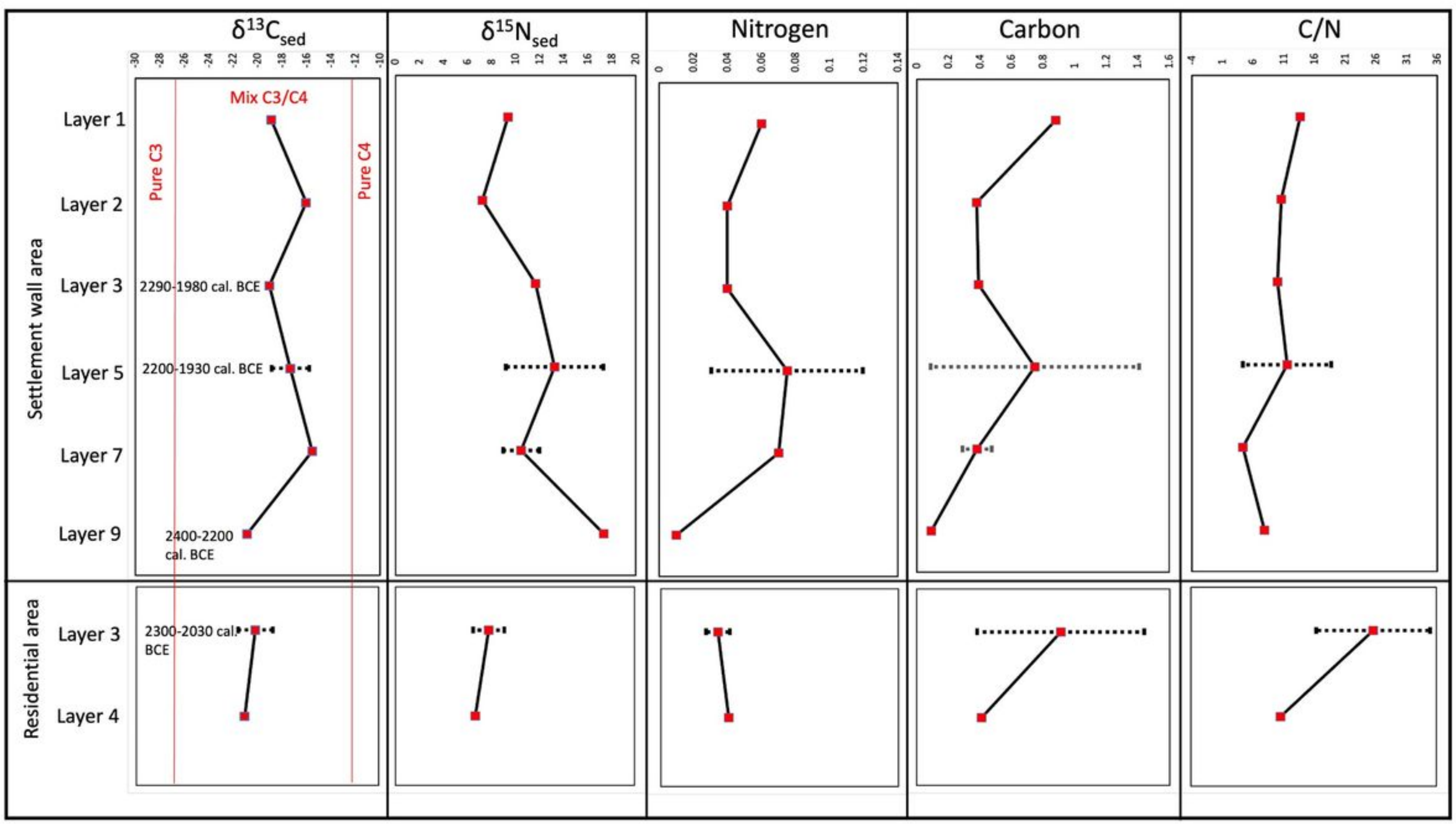

Figure 8

Isotopic and elemental data of sediments from Kotada Bhadli divided into residential area and settlement wall area. Layer 4 from the residential area and layer 9 from the settlement wall area are the pre-occupational layers, whereas layer 1 from the settlement wall area is the post-occupational layer. The C3 and C4 ranges displayed in the diagram are the global average obtained from (Kirkels et al., 2022).

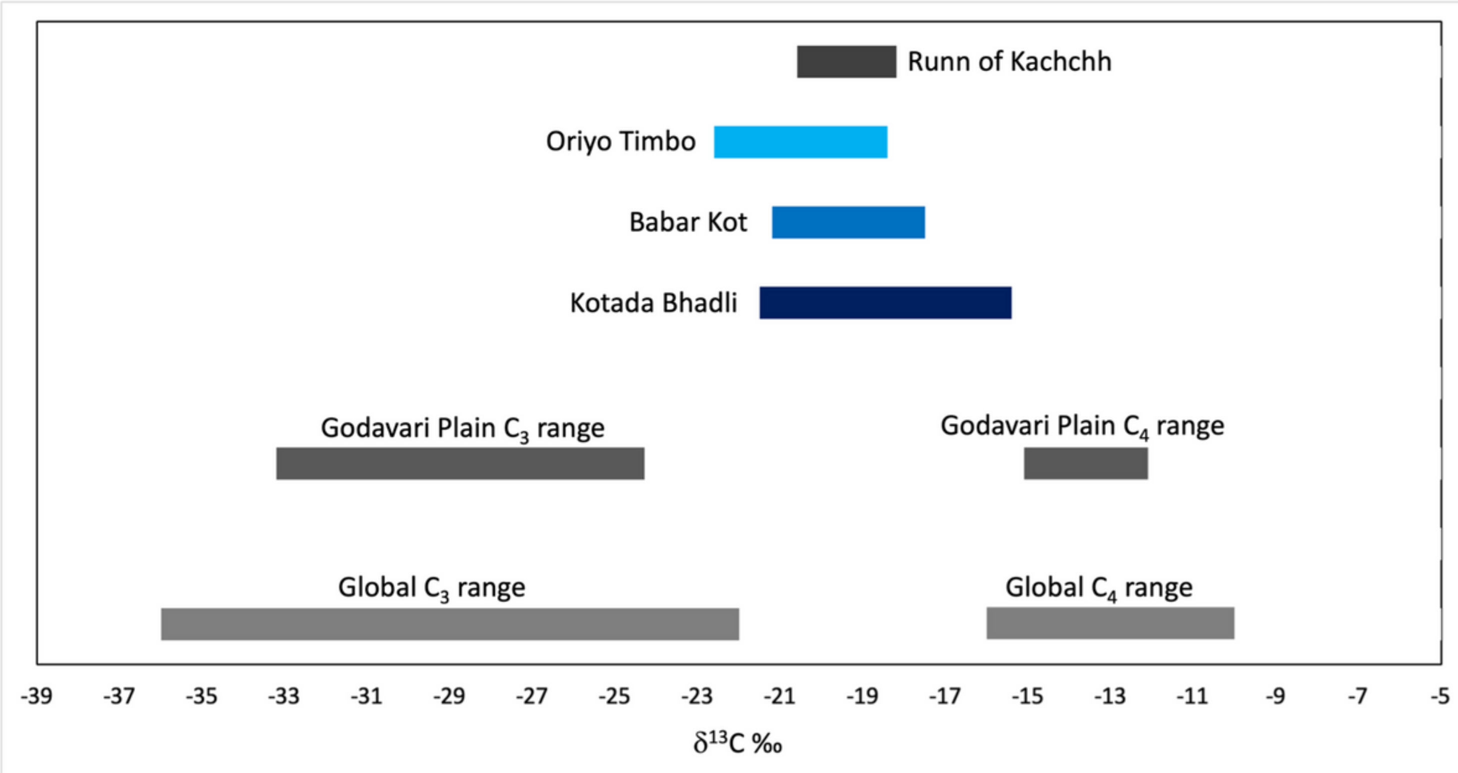

Figure 9

Comparison of d^{13}C$_{(sed)}$ values of Kotada Bhadli and contemporary settlements from Gujarat with global and local (Godavari) vegetation values. (d^{13}C values were obtained from (Dawson et al., 2002; Hare et al., 2018; Kirkels et al., 2022; Kohn, 2010; Ram et al., 2022; Reddy, 1994; G. Wang et al., 2008)