CASE STUDY

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Cartographies of warfare in the Indian subcontinent: Contextualizing archaeological and historical analysis through big data approaches

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Abstract
Some of the most notable human behavioral palimpsests result from warfare and its durable traces in the form of defensive architecture and strategic infrastructure. For premodern periods, this architecture is often understudied at the large scale, resulting in a lack of appreciation for the enormity of the costs and impacts of military spending over the course of human history. In this article, we compare the information gleaned from the study of the fortified cities of the Early Historic period of the Indian subcontinent (c. 3rd century BCE to 4th century CE) with the precolonial medieval era (9-17th centuries CE). Utilizing in-depth archaeological and historical studies along with local sightings and citizen-science blogs to create a comprehensive data set and map series in a "big-data" approach that makes use of heterogeneous data sets and presence-absence criteria, we discuss how the architecture of warfare shifted from an emphasis on urban defense in the Early Historic period to an emphasis on territorial offense and defense in the medieval period. Many medieval fortifications are known from only local reports and have minimal identifying information but can still be studied in the aggregate using a least-shared denominator approach to quantification and mapping.

Keywords Archaeology, Warfare, Cartography, Indian subcontinent, Fortifications, Heritage, Big Data, Data uncertainty

Introduction

Warfare has a landscape effect long before fighting begins and long after combat has subsided. While the preparation for warfare results in defensive architecture that provides a rallying point of refuge and a base of operations for military personnel, much of the long-term impact of warfare occurs through the ongoing effects of physical emplacements. Active fortifications, military bases, and outposts continue to constitute an essential component of state-making and political control in the modern world, while leaving durable traces that enable the assessment of past military outlays. Fortifications (defined as walled, defensible and strategically placed localities) are costly to implement and relatively difficult to efface; especially when located in remote areas, there is little impetus to remove them. Like other forms of state-sponsored infrastructure (such as roads), fortifications and military installations serve as a physical record of cost-benefit analysis and risk management [1] and as an ongoing silent sentinel of political authority [2].

The Indian subcontinent has perhaps the densest accumulation of premodern fortifications of any global region. Represented by the present-day countries of India, Pakistan, Bangladesh, and Nepal, the South Asian region has a legacy of over four thousand years of defensive architecture represented by thousands of fortifications. Over time, the construction of fortifications shifted from the construction of city walls to the creation of fortifications in the countryside, as chiefdoms and states grew in territorial strength to encompass not only nodes of population but also the concept of borders and boundaries that outlined ambitions of territorial control [3, 4]. Starting in the medieval period (c. 9th century CE), the subcontinent experienced a boom in defensive architecture in the form of fortifications in remote rural areas constituting a significant expenditure of resources [5–8] (Fig. 1).

The development of so many fortifications in South Asia, by so many different rulers and groups, indicates a significant allocation of resources and outlay of labor. Understanding the political implications of the development of a fort-studded countryside, in a land where such rural constructions were practically nonexistent prior to c. 8th century CE, first necessitates an assessment of their location. Yet the number of such sites is so large and the knowledge of individual sites so variable that the creation of subcontinental-scale maps of fortifications – essential as a framing device for hypothesizing the role of political power and engineering prowess – has never yet been undertaken. In this article, we provide the example of utilizing inputs of variable quality and a least-common denominator of information from each fortification site in order to provide a data set that can be used to demonstrate redundancy of construction as a deliberate – and likely symbolic -- form of military investment. The data set, displayed in cartographic as well

Fig. 1 Examples of medieval fortifications in South Asia, clockwise from top left: Gwalior (Bridgemanimages.com); Yadgir (M.L. Smith photo); Purandar, with the fortification of Vajragad on adjacent hillside (flickr.com/photos/msphadke/6,423,282,401); Gingee (Alamy.com BBAHDP)

as tabular form, also provides the basis from which new hypotheses of political amalgamation and new programs of local and regional investigation can be undertaken.

Archaeological and historical approaches to data.

Archaeological research consists of recovering physical remains such as artifacts and architecture through excavations and landscape survey; archaeologists also make use of remote-sensing techniques such as ground-penetrating radar, satellite imagery, and LiDAR to create information about patterns of human landscape modifications on the basis of visual perceptions that can afterwards be ground-truthed through field observations [9–11]. Archaeologists are attentive to elucidating chronology to enable the assessment of social and economic activities within specific time periods, as well as an assessment of changes over time as societies adopt new technologies, as people migrate in or out of areas in response to changes in environmental conditions, and as settlements grow or decline in size [12, 13]. Archaeological research provides specific opportunities for expanding our understanding of human societies in being the only way to learn about pre-literate cultures, as well as addressing many aspects of literate societies that are not written down, such as the diversity and social configurations of non-ruling populations. Archaeological research is conditioned by specific constraints: some regions are more thoroughly studied than others; some types of artifacts and architecture degrade and are therefore "invisible" [9, 14].

Historical research consists of the eliciting of singular narratives as well as patterns of collective action from written sources. Texts can emanate from elite individuals' actions (e.g., a royal charter or legal code) as well as ordinary peoples' wills, letters, diaries, law cases, receipts, gravestones, and probate inventories (e.g., [15]). Texts also emanate from broadly disseminated information of a kind that was subsequently recorded in written form (e.g., songs, poems, folk narratives, incantations). Some texts exist only in single exemplars, such as stone inscriptions meant to be a unique and prominent record of specific events, and some texts exist in multiples, for example on coins or on papyrus or paper onto which text is copied by hand or by machine. The study of large-scale phenomena necessitates both a generalizing perspective on social change and the consideration of individuals and events that changed the course of history in subtle or significant ways, resulting in a *longue durée* capacity in which historians telescope large amounts of information into a narrative of change and development over time [16, 17].

For historians, as for archaeologists, a single object, document, or phrase can form the focal point of an explanatory narrative, but the development of the background against which any exemplar is compared has, until recently, largely depended on individual researchers' skills and memory capacity [18]. Large-scale, computer-aided mechanisms are required in order to expand intellectual and analytic perspectives in ways that also democratize access to information and provide opportunities for alternate readings of the material and textual records [19]. Such an approach fulfills the concept of "Big Data," a concept that has multiple definitions but is often characterized by the "Three Vs" (volume, velocity, and variety) within a context of data storage and data analysis [19, 20]. Although Big Data is typically regarded as data too large to be manually processed, there is no formal definition of Big Data and data sets can vary significantly in terms of volume.

Regardless of the actual size of the data set, a "big data" perspective has three distinct intellectual outcomes: the ability to surpass the limitations of the extent to which pattern recognition can be ascertained by a single individual; the creation of replicable data sets that have explicit structures of data capture that make both the inputs of a data set and the outcomes of data searches standardized and repeatable (cf. [21]); and the creation of data sets that are available for others to use as the basis for augmentations that address new research questions [10]. A "big data" perspective also has two distinct analytic outcomes: large data sets enable the identification and subsequent analysis of anomalies either as significant or insignificant outliers [12]; and the use of standardized data for queries enables a more rigorous testing of *gestalt* or idiosyncratic impressions from fieldwork and lab work. A "big-data" approach also has a practical managerial outcome: researchers, government agencies, and funders are pressing for data-management plans for archaeological and historical information that allow for the preservation of physical objects and digital data as a component of heritage management [10, 22].

"Big Data" constructions are not inert but stand as the collective accumulation of information that is always increasing in size and scope, lending the possibility of new research questions as well as reaffirming the rationales of the initial development of the big-data data set. Yet there are challenges in creating "big data" in the social sciences and humanities that are distinct from the challenges of creating "big data" in the physical sciences. Archaeological data emanates from individual research projects and there can be a lack of standardization even in basic categories relating to the nomenclature of artifacts, features, and sites, necessitating that individuals seeking to create large data sets create (or assume) equivalencies across categories of observations (to be fair, the challenges of initiating shared regional nomenclature and data collection strategies exist in nearly all other fields that have initiated big-data approaches, including biology [23], museology [24], management [25] and neuroscience [26]).

Although some archaeological metaprojects have deliberately sought to increase data comparability by proposing regional standards prior to data collection [27, 28], the concept of a regional data-collection framework, while widely recognized as advantageous for large-scale analysis, remains difficult to implement [29, 30]. As a result, "data mining" in archaeology is a process undertaken by individual human workers who transform qualitative data (including historical texts and artifact and site descriptions) into quantified rubrics and spreadsheets that can afterwards be depicted graphically as outcomes of research and as platforms for subsequent hypothesis-building and analysis (e.g., [10, 22, 31, 32]. Single-investigator and single-team rubrics of data collection can provide a "sweet spot" of data streamlining in which a specific research question guides the creation of a spreadsheet in which each line of information is coded to capture a particular kind of quantifiable data. By using human-based extraction and quantification strategies, archaeologists have amalgamated multiple projects' data sets to address landscape-level patterns of human activities [13, 30], urbanism and settlement scaling [31], migration [33, 34], the origins of inequality [35], the development of sociopolitical complexity [36], and the heterogenous effects of disease in ancient times [37].

Cartography remains an essential component of historical and archaeological processes of interpretation and the generation of subsequent hypotheses. Despite the known limitations of the 'dots on a map' approach [29, 38, 39], maps as a form of data visualization provide a summation of known knowledge as an essential basis upon which to engage in higher-order analysis and to identify areas for further research (e.g., [12, 22, 40–43]. Numerous amalgamated archival repositories have been developed such as tDAR (the Digital Archaeological Record), DINAA (Digital Index of North American Archaeology), and Open Context [44], all of which encompass maps as an essential background for questions about both change and stasis in the past. Our research on the hypothesis and demonstration of political changes between two different eras in the Indian subcontinent, as measured through the distribution of urban and rural fortifications, necessitated map-making. The relatively small number of urban settlements in the Early Historic period ($n<100$) was straightforward, but the mapping of medieval fortifications (measuring in the thousands) required a different approach.

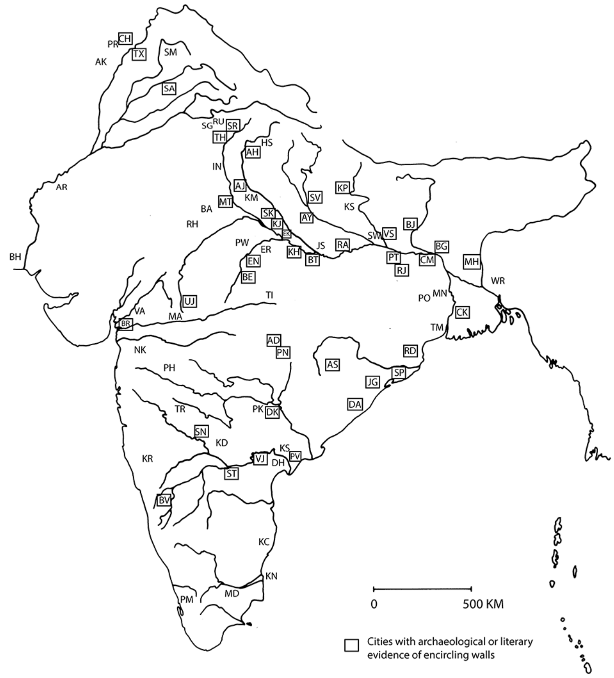
Landscapes of settlement and warfare in South Asia.

The Indian subcontinent was initially occupied by stone-tool-using hominins starting as early as 1.7 mya [45], followed by many thousands of years of forager lifeways and the subsequent development of agricultural villages in the Holocene. In the Bronze Age c. 2500−1900 BCE, the area that is now Pakistan and northwestern India was the home of the Indus (Harappan) culture, supported by wheat and barley agriculture and characterized by towns and cities as well as long-distance exchange [42, 46]. After the Indus period there was a hiatus of urban settlement and a dispersal of population into farming cultures associated with a shift to rice production, and in some areas, extensive collections of megaliths associated with communal memory and ritual burials (e.g., [47]). Significant population changes occurred starting c. 8th century BCE when people once again coalesced into cities interconnected with networks of trade and pilgrimage associated with new religious traditions such as Buddhism and Jainism, accompanied by the development of decipherable scripts starting in the third century BCE [48, 49].

For the Early Historic period, there are approximately 80–100 sites that can be characterized as "urban" on the basis of site size [49–55]. Many of these sites also are known from the historical record and have had significant amounts of investigations (although not all have been subjected to excavations). Significant changes occurred after the Early Historic period, marked by an abandonment of cities [50], a decline of coinage and other markers of long-distance exchange [56], and shifts in religious ideology including a return to and strengthening of hierarchical religious practices [57]. At the same time, there was a growth of small and large political entities that increasingly invested in the infrastructure of conflict and territorial management in the transition from the Early Historic period to the medieval era. The differences between the two time periods provide an opportunity to address the relationship of sites and their infrastructure within different territorial configurations of political control. Yet the evidence for social and political cohesion as seen in artifacts, texts, and sites is significantly different for each of the two eras. Studying the Early Historic period is amenable to simple map-making on the basis of widely available data to illustrate the extent to which urban settlements had encircling walls indicating that they were fortified or not fortified; Figs. 2 and 3.

The study of fortifications necessitated a different approach for the medieval period, where fortifications included walled localities that made use of topographically challenging locales. Compared to the archaeological study of the Early Historic era, there is a patchwork of knowledge about the medieval period for which there has been much more textual study than archaeological analysis [58, 59]. Nor is archaeological research for the study of this era a straightforward exercise. Although the Indian subcontinent is one of the most populated areas in the world today, many portions of the region are still difficult to access and inhabit, particularly in rugged locations that are far from modern

Site name	Location
Adam	AD
Ahichchhatra	AH
Akra	AK
Aror	AR
Asurgarh	AS
Atranjikhera	AJ
Ayodhya (Saketa)	AY
Bairat	BA
Balirajgarh	BJ
Banbhore	BH
Banavasi	BV
Bangarh	BG
Besnagar (Vidisa)	BE
Bhita	BT
Broach	BR
Campa (Champa)	CM
Chandraketugarh	CK
Charsada	CH
Dantapuram	DA
Dharanikota	DH
Dhulikatta	DK
Ekachakra (Chakranagar)	EK
Eran	EN
Erich	ER
Hastinapura	HS
Indraprastha	IN
Jaugadh	JG
Jhusi	JS
Kampilya	KM
Kanauj	KJ
Kanchipuram	KC
Kapilavastu (Tilaurakot)	KP
Kaushambi	KH
Kaveripattinam	KN
Kesarapalle	KS
Kondapur	KD
Kolhapur (Brahmapuri)	KR
Kusinagara	KS



Site name	Location
Madurai	MD
Mahasthangarh	MH
Mahismati (Maheshwar)	MA
Mangalkot	MN
Mathura	MT
Nashik	NK
Paithan	PH
Pataliputra (Patna)	PT
Pattanam	PM
Pauni	PN
Pawaya	PW
Peddabankur	PK
Peddavengi	PV
Pokharna (Pakhanna)	PO
Purushpura (Peshawar)	PR
Radhanagar	RD
Rairh	RH
Rajghat (Varanasi)	RA
Rajgir	RJ
Rupar (Rupnagar)	RU
Sanghol	SG
Sankisa	SK
Sannathi	SN
Satanikota	ST
Semthan	SM
Sakala (Sialkot)	SA
Sisupalgarh	SP
Siswania	SW
Srughna (Sugh)	SR
Sravasti (Saheth-Maheth)	SV
Tamluk (Tamralipti)	TM
Taxila	TX
Ter	TR
Thaneshwar (Kurukshetra)	TH
Tripuri	TI
Ujjain	UJ
Vadapadraka (Vodadara)	VA
Vaisali	VS
Vijayapuri	VJ
Wari-Bateshwar	WR

Fig. 2 Urban settlements of the Early Historic period, showing settlements that have encircling walls (c. 3rd century BCE-4th century CE)

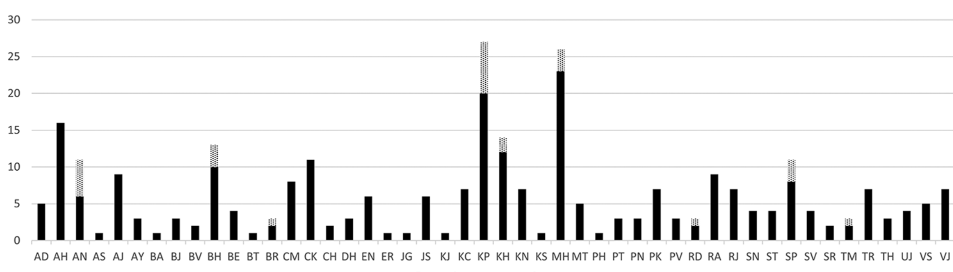


Fig. 3 Estimated number of seasons of fieldwork at urban sites of the Early Historic period

settlements. The challenges of constructing military infrastructure in these remote locations did not, however, impede premodern rulers from such activities, and the results of their efforts are widespread in the landscape. Indeed, forts are so numerous that many of them have had no formal archaeological or historical investigations of any kind. For example, Rawat et al. in their study of 193 fortifications in the Garhwal Himalaya region of northern India noted that only one has had any excavations, and only ten had any description in the academic literature [60]. As a result, many forts in the subcontinent are known only from local knowledge, social media, and news reports [60, 61].

Even when excavations have been conducted, comprehensive analyses have been lacking; one example is the spectacular site of Banbhore, about which a recent summary article noted the following about the excavations undertaken by F.A. Khan from 1958-65:

> *"Unfortunately, all we have of Khan's campaign is a first map of the 'citadel' and its encircling towered walls, a booklet (1st edition 1963) and a few articles in Pakistan Archaeology by the same scholar and his collaborators…The chronological layers of the site have been left unstudied and unpublished: excavation notes, stratigraphic*

sequences and drawings have disappeared; nobody seems to know where they are. Some lingas and a great amount of ceramics, properly stored and classified in the storerooms adjoining the Site Museum of Banbhore, have never been analyzed. There has never been any precise indication of the trenches and layers where they were unearthed" [62].

The site of Banbhore has been investigated in more recent years by a team of French archaeologists and by a team of Italians working with their Pakistani colleagues, a factor that introduces more data but also more languages of interpretation (for a total of at least four: Urdu, English, French, and Italian) to the compendium of site analysis. The result is at least 13 years of investigation including at least 10 seasons of excavations, and yet, the complexities of the site (and a high water table that inundates the lowest levels of occupation) means that we still do not have basic information about the first settlement of the site [62].

Throughout the subcontinent, fortifications are materially changing due to incremental vegetation growth and the pressures of modern land development, natural disasters, and climate-induced accelerations of landscape change. Hence, some of the information about fortifications is as good as it will ever be; in other cases, information about sites will improve over time but must still be incorporated into the larger picture of the subcontinent as a whole. Satellite imagery (including Google Earth) provides opportunities to identify human-made constructions in rugged or remote areas; it should be noted that due to factors of cost and government permissions, LiDAR studies are not yet widespread in the subcontinent. Ground-truthing techniques of excavation and survey should eventually allow for identifications of chronology, although this is not a straightforward process. Challenges of access are a considerable problem in the study of fortifications in the Indian subcontinent; some are located in sensitive areas that are under current military control, and many are overgrown with vegetation that conceals the presence of snakes and other deterrents to field investigation (e.g., [63, 64].

Even when fortifications are easily accessed, chronological study is challenging. Fortifications often were inhabited by only a small number of people and generally did not accumulate the discards of workaday habitations of the type that would indicate an era of construction or use (cf. [65]). The construction techniques of stone walls rarely have any datable materials incorporated into them such as wood that would be suitable for dendrochronology or radiocarbon dating; a rare exception is the use of wood that allowed for dendrochronology at two Nepalese forts [66]. Exceptions might be the use of mortar in construction that incidentally includes datable materials such as pottery sherds, although the dating of most vessels in the Indian subcontinent is also less than precise, especially the coarse and plain pottery associated with the expedient provisioning of military encampments (for an example of the painstaking work required to differentiate medieval vessels, see [67]). In any case, the appearance of a datable sherd within mortar would be only a *terminus post quem* (earliest potential construction date) and could have been incorporated many centuries after the actual construction of the wall (cf. [9]). Dating through changes in architectural style (whether the shape of building materials or the shape of the fort) can also help to identify construction phases. However, augmentations generally completely subsume the earliest structures, making it difficult to identify specific phases of construction. In rare cases, a wall or gateway is inscribed with a construction date (e.g., at Bidar), which provides information about singular actions (although fortifications are often modified by subsequent rulers, and again such modifications are rarely mentioned in the textual record [7, 8, 60]).

Methodology.

Our research about continental-scale investments in military activities in the medieval period of South Asia parallels other emergent uses of Big Data in archaeology. To render qualitative data (including observations from nearly two centuries ago to the present) into quantitative form, we focused on parameters of site name, location, and chronology that let us maximize the representation of sites whether or not they had ever been documented in any detail. Our approach to creating the data set of medieval South Asian forts was deliberately simple, in part because there is not an abundance of archaeological and historical data consistently available from all sites, as noted above. Records of fortifications in the Indian subcontinent exist at a variety of scales: archaeological investigations of a small number of exemplars, including survey as well as a very limited number of excavations, and historical documents of fortifications (and their battles). This heterogeneity of academically generated information is counterbalanced by information in other sources given that fortifications are of considerable interest to the public today, forming an element of "citizen science" [68] investigations, photography, and lists of the type that appear in online sources such as personal web pages, YouTube videos, and Wikipedia entries. The democratization of the search for and documentation of fortifications provides a more comprehensive, if minimalist, set of information about the location of fortifications in the subcontinent (cf. [22]).

We consulted encyclopedias, books, and internet sources about fortifications located in the contiguous South Asian countries of Bangladesh, India, Nepal, and Pakistan [5–8, 62, 69–79]. This process yielded a list of 3,863 fortifications (46 in Bangladesh; 3,726 in India; 40 in Nepal; and 51 in Pakistan). Because fortifications are large and distinctive entities, we can be fairly certain that relatively few such fortifications in India remain undiscovered (in comparison to other types of settlement sites, which continue to be discovered through archaeological research); however, there may well be more fortifications in Pakistan that have yet to be recorded or that our research methods did not capture. We constructed our data set to capture two types of information for each fortification: location in geographic coordinates and any chronological data (general era of construction, whether available to the precision of a particular date or century, or a broad general era such as "ancient" or "medieval"). Even with these generous basics, there were many sites that fulfilled only the locational criteria rather than chronological criteria, given that many sites, even very substantial ones, have been labeled by local research scholars as being of "unclear" date.

Consolidation of the diverse fortification reference material required the creation of a tabular database to log individual sites. We utilized the Microsoft Excel program to enter data, on the logic that (a) Excel is widely available in the subcontinent and elsewhere, enabling in-country users to access our tallied data (b) Excel is ubiquitous, well-established, and backwards-compatible, with a high probability of continuing to be readable in future. The use of an Excel spreadsheet, which can easily be inserted into data management and visualization programs, helps to overcome one of the challenges of big-data acquisition in archaeology and history, in which there is the risk of overlapping, mutually incompatible systems of digital entry that are incompatible with long-term or multi-user research goals [12, 18, 44]. Information about fortifications was entered into the tabular database by this paper's second author, who inserted the name of the fort, location (which often included only a relative position compared to the fort's local district headquarters, as well as district, state/province, and country), and geographic coordinates. Latitude and longitude were found on Google Earth and through coordinate information provided in the written sources. Visual scans were used on satellite imagery to identify sites in which relative location was provided but exact position was not, an approach that follows Huynh et al's [80] observation that human eyes are superior to machine-learning for pattern recognition in complicated environments (see also [12] on the effectiveness of "manual cleaning" and "qualitative assessment" in dataset construction).

The century of fortification completion and era of use were also included if available, although most did not have dates provided in the texts or were listed as unclear. Only 714 of the fortifications in our list generated from published sources had dates offered; from this we removed forts of the pre-medieval period ($n=33$) and post-medieval period (18th century and later, $n=152$) for a total of 530 forts of 9-17th century date (what we describe as the broadly "medieval" period). The tabular data set of both fortifications labeled "medieval" and without listed dates was imported into Esri's ArcGIS Pro and converted to a point feature class based on the coordinate information, using the XY Table to Point tool. 3,678 points were rendered. A generalized shapefile of world countries (data source: Esri ArcGIS Hub) was opened in the map viewer and filtered for states within the scope of our geographic interest. Given that these fortifications were established prior to any of the nation states in the South Asia region, we removed country borders. Including country borders and analyzing the spatial relationship between fortifications and these borders could provide valuable insights into state formation and the long-term processes of defining cultural area boundaries. However, we decided this was beyond the scope of our database creation, especially because of the often contentious nature of borders.

Figure 4 illustrates those sites for which there was an indicator of a date (of construction or use) within the broad category of the "medieval" era (9-17th centuries CE). This was produced by creating a definition query for records with a date of construction value that was not null. Although a few forts had extensive historical records that allowed for an understanding of change over time, we needed to rely on undated or unclear dated materials in order to make a coherent map, maximize analytic potential, and best assess the spatial distribution of fortifications on the landscape. Figure 5 contains the much larger data set of both dated fortifications and fortifications for which the dating was unstated or undetermined. Figure 5's vastly larger distribution of sites graphically illustrates the intensity of fortifications in the subcontinent when all presence-absence data are included. Another goal was to cartographically illustrate the redundancy in fort establishment. The geoprocessing tools of Buffer and Select By Location > Intersect were used to accomplish this. The result is Fig. 6, which shows the spatial distribution of fortifications within 3 km of another fortification.

Small Data and Big Data.

The creation of any big-data approach necessitates not only a backwards view to prior projects in the creation of an amalgamated data set, but also encumbers the structure of future research that is designed to be inserted into an already-extant database [18, 26]. Our data set's low volume, as compared to other research in this journal and in the

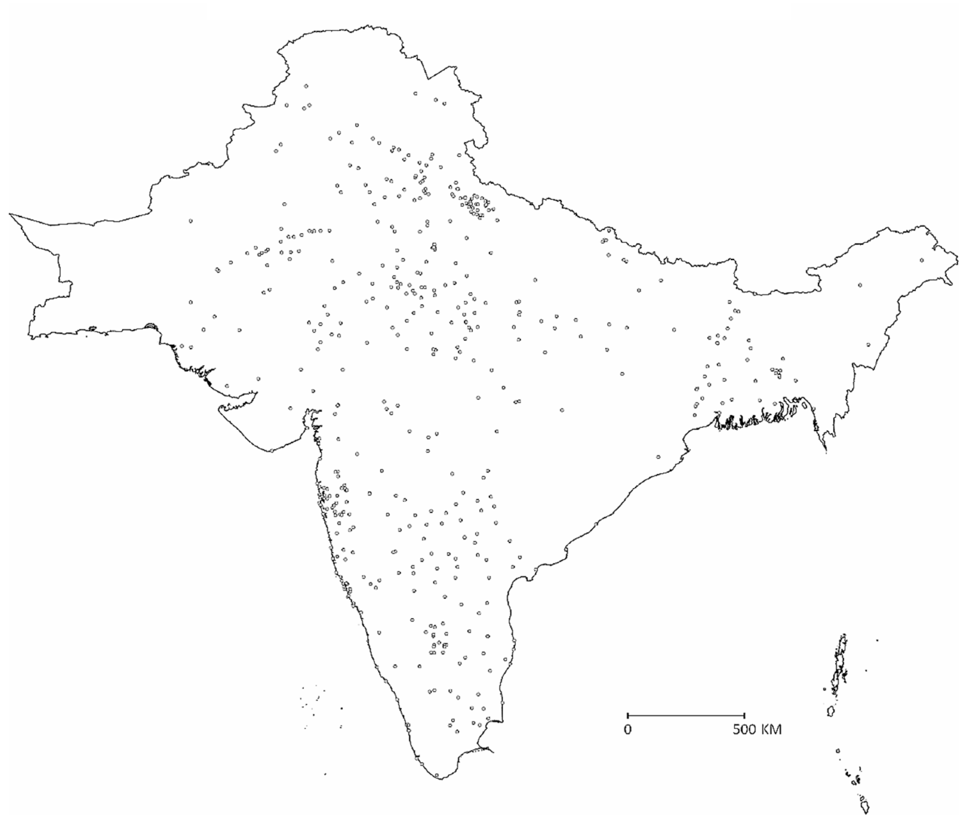


Fig. 4 Fortifications in South Asia with historical or archaeological dates that indicate medieval construction and use (9-17th centuries), $n = 530$

broader universe of Big Data, suggests that while our data set of ($n < 4{,}000$ examples) may be considered "small" it remains intrinsically connected to Big Data fundamentals. We did not use machine learning, statistical algorithms, data mining, or automation in our process, but we are encoding a Big Data perspective onto our small data by leveraging modern data handling techniques and tools. This approach, using human eyes to code and collate data into a large, queryable and mappable format, mirrors the amalgamation processes of other data-collection strategies in the social sciences and humanities (e.g. [12, 31]).

The relative value of our amalgamated data on medieval fortifications at the subcontinental scale can be made through comparisons with "small data" approaches to the same region. One small-data comparative grouping is the set of less than a hundred known urban settlements of the Early Historic (4th c. BCE-3rd c. CE) period. Approximately 55% of urban settlements of that period were equipped by their inhabitants with encircling walls [4, 55, 81]. Many factors must have entered into ancient peoples' cost-benefit analysis of making a city walled for the purposes of defense, flood protection, taxation, or regulation of trade, but there are few historical records related to the construction and occupation of sites meaning that archaeological investigation is the only way of knowing about labor investments and the chronology of construction. Early Historic urban settlements have had variable amounts and quality of archaeological investigation (ranging from virtually no fieldwork to many years of excavations, and recording strategies that go from the minimalist descriptive prose of the 19th century to intensive, state-of-the-art documentation), but the study of fortifications is relatively straightforward given

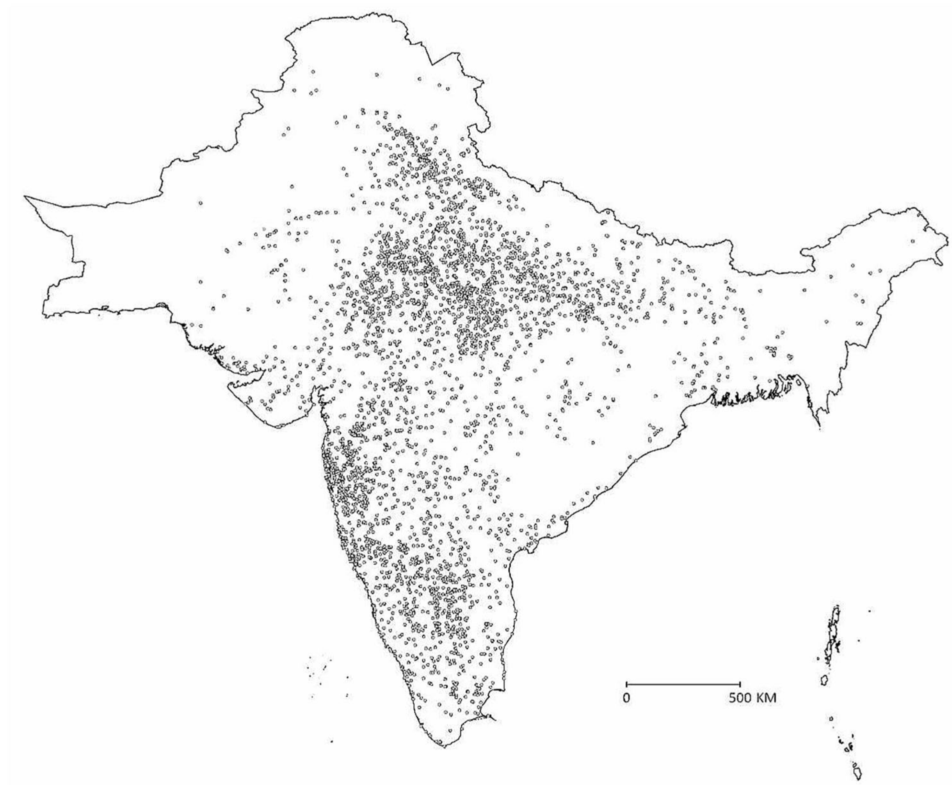


Fig. 5 Fortifications in South Asia that include both dated medieval fortifications and fortifications for which dates are unknown, *n* = 3,678

that many of these sites' defensive outlines are still visible in satellite imagery (e.g., [82]). Although the quantity of information about artifacts and structures in the different sites would certainly benefit from a more standardized mode, computational comparison will always be difficult given the disparity of information from each site, such that presence-absence comparisons are still rewarding.

Another "small data" approach can be found in the work of Rawat et al. [60], who examined medieval fortifications of the Garhwal Himalaya region of what is present-day Uttarakhand state in India. The construction of their data set was hampered by the same constraints that we also faced in the aggregation of medieval fortifications throughout the subcontinent, such as variable site names for the same locality and variable quantities of information about any particular site. Chronology was also challenging for them to establish. Given the lack of firm historical or archaeological dates, they made the parsimonious assumption that general historical records related to the existence of fortifications in the 12-15th centuries was sufficient to classify all of the fortifications in their study area as being of that time period. Despite the challenges of creating even a basic data set of locations, their work nonetheless provided the opportunity to consider how fortifications functioned as nodal points in the medieval political systems of the Himalayan foothills. Utilizing previously published research, local interviews, and archaeological survey fieldwork, they created a GIS-based map to ascertain whether rural fortifications promoted communication through intervisibility and suggested how fortifications contributed more to the landscape than a mere "military" function.

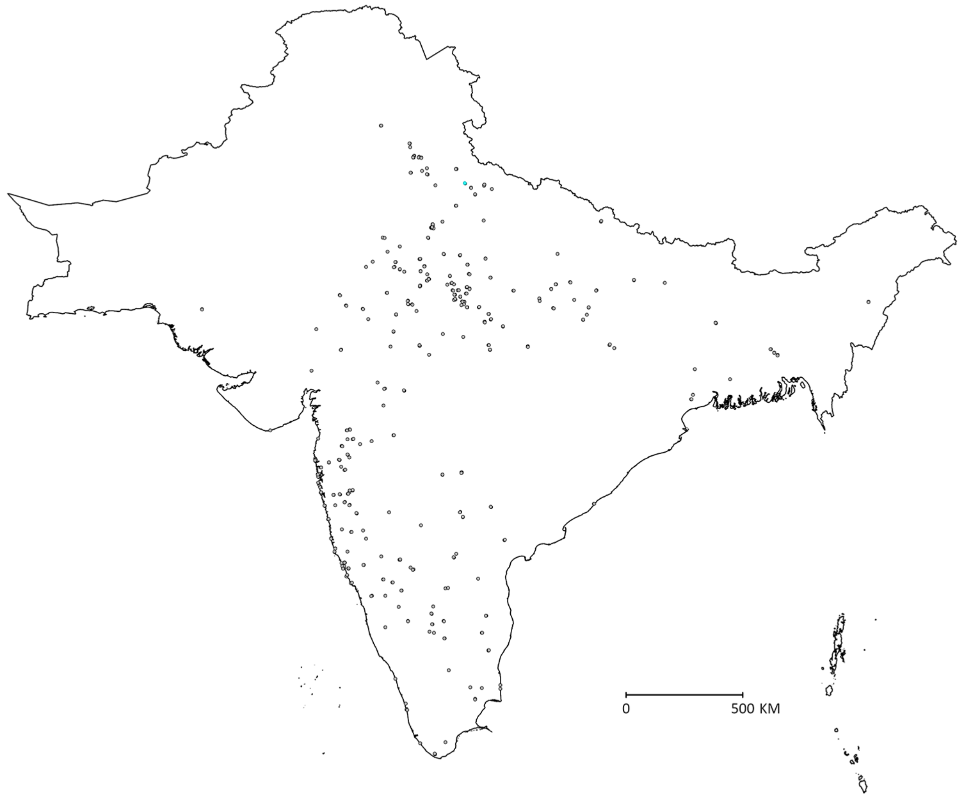


Fig. 6 Fortifications in South Asia within 3 km of another fortification ($n = 533$)

Our data set created of medieval forts at the subcontinental level could be viewed as encoding a "small data" approach within a "big data" perspective. As consistently noted by scholars of archaeological and historical data amalgamations, there are many idiosyncratic and qualitative observations that occur in the course of examining individual points of data, whether in the field at the point of discovery, or in the subsequent processes of data entry and data management [18, 25, 83]. While every site occupies a "unique" position in a landscape or on a map, sentient researchers (as opposed to AI or LLM data-scraping practices) will engage in pattern recognition that adds richness to interpretive approaches. In the course of creating the tabular data set for this paper, many such patterns were noted. Although the vast majority of medieval forts were in areas far from settlement, some cities developed in a circular formation around land forts, such as the Bhadra Fort in Ahmedabad, Gujarat, which was built in 1411 and was among the first structures in the city. Walls and bastions expanded the fort for the following centuries, and a city was built within a several mile radius surrounding the Sabarmati River. Purana Qila, which occupies a mound in the center of Delhi, and Vijayanagar Fort at Thanjavur in Tamil Nadu are similar. Many hilltop forts seem to be generally well preserved, likely due to a lack of development and relative inaccessibility (such as the bastions and walls of Panchawara Hill forts 1 and 2 which are still highly visible with satellite imagery; Vijaygarh Fort in Uttar Pradesh, though now obscured with vegetation, which has well-preserved walls and columns; and the UNESCO World Heritage Site of Kumbalgarh Fort, with its walls extending 36 km).

Regional analyses of political developments illustrate that any fort-building activity by a political unit was undertaken at a time in which competing political groups were also building forts at a rapid pace, sometimes to the point of redundancy due to the extreme proximity of defensible locations. The proliferation of fortifications among competing territorial entities constituted a landscape-scale arms race of a kind with which we are familiar today, in which innovation, abundance, redundancy and excess are deliberate aspects of military preparation and political statecraft. Historical documents, when they are available, indicate the amount of time and labor invested in the construction of fortifications, such that a single "dot" on a map often encompassed decades of construction and centuries of use. For example, Agra Fort was started in 1564 by the Mughal ruler Akbar but not completed until 1605, some 40 years later [7]. The fort of Gingee, in the southern Indian state of Tamil Nadu, illustrates the way in which a fortified locale endured as a focal point of vastly different ruling entities. Gingee encompasses three natural hills, and probably had some defensive investment in the Chola period prior to c. 1250 CE; it was augmented by a king of Tanjore in 1442, then by the Vijayanagar kings in the 16th century, captured by the Maratha ruler Shivaji in 1677 and in the following century was sequentially controlled by the Mughals, the French, and the British [7].

Analysis and Discussion.

By rendering both traditionally published academic information and contemporary observations into quantified formats, our approach fulfills the concept of big data as a "technical movement which incorporates ideas, new and old" [19] for the study of premodern human behavioural patterns. In addition to demonstrating the concentrated intensity of fortifications in the Indian subcontinent in the medieval period, our cartographic project provides several prospects for future research through an approach that encompasses the categories of (relative) volume, velocity, and variety within a big data format.

One future research question relates to the extent to which a specific historical threshold of population or political hierarchy was necessary for rural fortifications to be a viable component of statecraft. The earliest rural fortifications in the Indian subcontinent appear to date to the 8th century CE and later, insofar as historical or archaeological records provide dates. These include the fort of Chitorgarh in western India, dated to the 8th century CE [7] and Gingee in the far south of India [5]. Given that many of the Early Historic cities experienced at least a pause of occupation, or outright abandonment, around the 4th century CE [50], another obvious question that ensues is whether the initial formations of states from the 4-7th centuries CE were still largely concentrated on the consolidation of local resources (e.g. through the construction of religious structures and the advent of bureaucratic mechanisms such as land grants) rather than through the growth of territories marked by the expenditure of resources in remote areas through fortifications. The period of time from the 4-7th centuries CE is described as by Hawkes and Casile as "particularly transformative" in the subcontinent [29] and may well have been organized politically and socially in very different ways from both the urban-focused era that preceded it and the territorially expansive political configurations of the medieval period that came afterwards starting in the 9th century CE.

A second prospect for future research is a critical examination of the political conditions under which fortifications are installed, and how fortifications are linked to both political growth and fragmentation. In engineering and functional terms, fortifications are located in areas that can be described in the Venn diagram of convenient access (related to the supply chain of provisioning and labor) and the inconvenience of inaccessibility (related to defensibility, with inaccessibility often augmented by topographic placement). But in political and social terms, the emplacement of fortifications (and military bases in general) can be analyzed as proactive responses to growth or reactive responses against weakness. In the Indian subcontinent, an increase in the number of fortifications was sometimes prompted when the collapse of a regional polity resulted in the proliferation of small chiefdoms that each developed fortifications to protect themselves from the raids of competing local groups, e.g. in the Garhwal Himalaya region of northern India [60]. In other cases, an increase in the number of fortifications was part of a singular approach to territorial expansion and landscape management as it was under the ruler Chhatrapati Shivaji Maharaj of the Maratha period, who is credited with the possession, construction, or repair of 300 forts [6]. Rulers often also re-used, augmented, and modified the fortifications that they captured in order to strengthen their own control over territory, meaning that individual strongholds could be part of a cyclical pattern of local investment, state consolidation, and subsequent resistance.

A third outcome of the creation of the map and spreadsheet of fortifications in South Asia is to enable the understanding of relative labor investment and the capacity for a multiplicity of premodern uses that may have affected the placement of fortifications in the landscape. In their study of 193 forts in the Garhwal Himalaya region of India, Rawat et al. note that larger constructions tend to occur within a smaller topographic range than smaller fortifications, and that smaller fortifications are found at both higher and lower elevations [60]. This is likely to suggest a multi-use intent and capacity for smaller fortifications; low-elevation constructions in particular would have been amenable to use by travelers, merchants, religious pilgrims, and other civilians, while higher-elevation fortifications may have taken on a primarily religio-symbolic role after construction. A follow-up research project in other regions of concentrations of fortifications, ascertaining their relative size, could be efficiently carried out by proxy through the use of Google Earth, CORONA, or other satellite imagery [82], enabling the assessment of the extent to which seemingly single-purpose constructions for military intent may actually have been conceptualized as dual-use infrastructure.

A fourth outcome is the analysis of the extent to which defensible and military landscapes were redundantly invested in the historical past. Given that today's infrastructure is often configured with overflow capacities and fail-safe backups, a study of medieval fortifications similarly should take into account the labor investments in constructions that may never be "used" except as a contingency. Figure 6 shows the number of medieval fortifications that are within 3 linear km of another, illustrating cases such as the forts of Purandar and Vajragad, which are only 1.65 linear km apart (see also Fig. 1). Studies of pairs of forts may yield insights about why redundancies were of strategic or logistical importance in specific cases. A subsidiary question is the extent to which forts were unfinished due to changing political circumstances, or fully constructed but never "used" for military offense or defense. Confirming the non-completion of a fortification might be difficult, given that the natural assaults of wind and weather, along with cultural depredations such as stone-robbing for re-use in other constructions, means that many fortifications are not in good enough condition to know whether they were ever "complete." Ascertaining non-use of a presumably complete fortification would require fieldwork to ascertain whether there are any remains of daily-use goods of the kind that tend to be inexpensive, breakable, and easily disposed (such as pottery fragments or weaponry), or phosphates as the byproducts of human waste.

Related to the concept of redundancy is the possibility that certain landscapes might hold more fortifications than are currently known. Our spreadsheet of forts in the four countries of Bangladesh, India, Nepal and Pakistan revealed numbers that are deeply disproportional to landmass (Bangladesh: 8×10^{-4} per mile^2, India: 3×10^{-3} per mile^2, Nepal: 7×10^{-4} per mile^2, Pakistan: 1×10^{-4} per mile^2). India is only four times larger than Pakistan, but has over 70 times more recorded forts; while this means that Pakistan is likely to have as-yet unrecorded fortifications (or fortifications for which information is not easily available in English-language published sources), and there is a low likelihood of undiscovered forts in India, it does not mean that all defensive architecture in any region, even India, has been fully recorded. In addition, there are military installations that provide support services, including temporary fortifications and camps, that are essential for the conquest and defense of territory but that result in ephemeral remains (e.g., [65]). In their study area of the Garhwal Himalaya region of India, for example, Rawat et al. recognized two types of defensive architecture: "forts" (which numbered 36 of their 193 exemplars, all of which are included in our tally) and the much larger proportion of "fortalices" or smaller defensive outposts ($n=157$, which were not included in our tally) [60]. Many of the fortalices were recorded for the first time through their project, enriching the concept of interconnected medieval defensive architecture. Given that many fortalices are visible only through ground-truthing and local fieldwork, a large-scale map for identifying areas of potential research investment can be combined with additional GIS work to provide information for predictive modeling of the location of supplementary fortalice-type installations. For example, algorithm-based predictive analytics and the fusion with other regional archaeological databases (which do not yet exist for the most part) could reveal how the interconnections between fortifications supported networks of statecraft, settlement, and warfare. Additionally, data mining tools for satellite imagery could uncover previously undiscovered fortifications and other related archaeological sites, although these would still need to be ground-truthed or at least evaluated through human eyes remotely [30, 84].

The study of fortifications also can illustrate how states and other political authorities re-use infrastructure from one era to the next, often for very different purposes. Forts have continued to be sites of territorial control and governance: the British Raj used Ahmednagar Fort in Maharashtra as a prison, while Patiyali Fort in Patiyali, Uttar Pradesh houses many local government offices. Nauhjheel Banger in Uttar Pradesh, situated on a hill overlooking Naujhil, acts as the town's police station, and Kotwali Darwanza in West Bengal now includes an immigration office and customs station. In other cases, forts were augmented with showy palatial residences by their original builders or subsequent conquerors, a form of architectural embellishment that continues to add value to real estate. Rajasthan's Samode Fort, built in the early 16th century, was converted into a palace in the 19th century. Little of what was initially fortification remains, and the property is now a tourist attraction, film location, and luxury hotel. Dungarpur Old Palace, also in Rajasthan, and Raja Jaunpur Palace in Uttar Pradesh were once heavily fortified, but are now highly ornamented and serve as museums or heritage hotels.

A final outcome of the tallying and analysis of medieval fort distribution is to provide support for heritage management and conservation efforts of the type that add value to local economies. The South Asian countries altogether represent nearly one-quarter of the world's population, with corresponding pressures on land for settlement, agriculture, resource extraction, and recreation. Heritage and history are a focus of both domestic and international visitor interest, with domestic middle-class tourism particularly poised for growth due to the increasing availability of private vehicle transport and perceptions of leisure value in historical monuments [85, 86]. Local public interest in forts as places for tourism and leisure is already high, indicating a built-in constituency for the expansion of such experiences. For example, the number of visitors to the in-town fort of Shaniwarwada in the city of Pune (11.19 million in 2018) [87] and the in-town fort of Golconda in the city of Hyderabad (19.66 million in 2018) [88] can be compared with visitation to popular out-of-town forts such as Daulatabad (8.58 million in 2018, located 15 km from the nearest substantial population center) [89] and Sinhagad (340,000 in 2017, located 35 km from the nearest substantial population center) [90]. The curation and promotion of fortifications as an innovative focal point of tourism to lesser-known forts can provide new opportunities, such as trekking tours that can be interdigitated with points of interest in natural science such as geology, botany, bird-watching, and other forms of eco-tourism [91]. Fortifications might be well-known locally or easily identified on satellite images even if they lack academic note, being simply part of the environment (such as Sambyal Fort in the Jammu and Kashmir region and Hirakot Fort in Maharashtra state); greater attention to such forts as local points of reference can also validate locals inhabitants' interests in heritage management and protection.

Conclusion

The "context" of data from archaeological and historical research is manifold: the ancient context in which any site was occupied; the geological and cultural contexts of degradation and burial; the historical contexts of re-discovery and recording; and the modern contexts of data analysis and research questions, along with determinations of which sites are "important" enough for conservation and tourism. In the case of medieval fortifications of the Indian subcontinent, a millennium of construction and use has been augmented by differential availability of historical records and unevenly filtered through two centuries of archaeological investigation that have encompassed different standards of data recording that can nonetheless be streamlined into a standardized and queryable format.

Our project shows the value of utilizing information of variable quality in the creation of "big data" through amalgamation of presence-absence information from a variety of archaeological, historical, and contemporary sources. While our resultant map of sites for which chronological dates are offered is already an impressive demonstration of the role of fortifications in the subcontinent during the medieval period, the addition of sites that are of "unclear" date truly illustrate the extent to which the fortification of rural areas was a dominant strategy of state formation and political territorialization prior to the colonial period. In South Asia and elsewhere, a big-data approach to fortifications provides the basis for addressing large-scale change and the impact of incipient as well as actual warfare, in which the larger overall picture can also lend support for the intensive study of any single site of the type that is a likely subject of local interest or a single person's or team's academic research project. In this way, a big-data approach of overall patterning functions in the same way as big-data compilations in fields such as neurology, where trends and patterns can yield predictive results, participatory medicine, and better outcome for individual patients [26]. Although any single data point may be unreliable, the cumulative effect of variable information is sufficient to evaluate changes in warfare in the Indian subcontinent in addition to serving as a basis for further investigation and we fully welcome the use of the supplemental material as a basis for augmentation by future researchers.

Finally, big data about big sites enables us to appreciate that the complexities of the premodern world were neither minor nor inconsequential; the size and scope of fortifications in particular command respect from today's engineers and building contractors as well as from the general public. Fortifications are among the largest coherent single structures in the human architectural repertoire, being much larger than individual habitation structures, tombs, or megalithic monuments. Yet they remain understudied in many countries and often are overlooked if they are in rural or remote areas far from areas of tourism development potential. The sheer volume of fortifications from the ancient world nonetheless reminds us that warfare, conflict, strategic defense, infrastructure investment, and the "sunk costs" of planning for events that may never happen are not unique outcomes of present-day political life, but an ongoing component of the state-development process.

Supplementary Information

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Supplementary Material 1

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Author contributions

MLS and CN jointly developed the idea. MLS wrote the initial manuscript and CN contributed to multiple sections. MLS initiated the structure of the data set and CN created the data set and generated the figures. All authors read and approved the final manuscript.

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Data availability

Data is provided in the supplementary information files.

Declarations

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Competing interests

The authors declare no competing interests.

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