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Spatio-temporal analysis of the Indus urbanization

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The greater Indus valley was home to Neolithic cultures starting from 7000 BCE. They formed the antecedents of the urban Harappan civilization, whose rise and decline are dated to 2600 BCE and 1900 BCE respectively. At its peak, the Harappan civilization covered an area of more than a million square kilometres, making it the largest urbanized civilization of the Bronze Age. In this communication, we integrate GIS information on topography and hydrology with radiocarbon and archaeological dates of 1874 sites, to

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analyse the spatio-temporal growth and decline of the Indus urbanization. Our analysis reveals several large-scale patterns in the growth and decline of urbanism. In the growth phase, urbanism appears to nucleate in three distinct geographical locations, situated in Baluchistan, Gujarat and the Ghaggar–Hakra valley. In the mature phase when urbanism is fully developed, the area distribution of sites follows a Zipfian power law, a feature common to modern urban agglomerations. In the decline phase, the pace of de-urbanization is nonuniform with a strong geographical variation. The decline starts in the Ghaggar–Hakra region, followed by a large-scale collapse in the lower Indus plain, leaving, however, a resilient zone in Gujarat which has a delayed decline. The patterns discerned through our analysis will find use within a Bayesian framework to test hypotheses for the growth and decline of the Harappan civilization.

Keywords: Baluchistan, Ghaggar–Hakra region, Harappan civilization, Indus urbanization.

THE Harappan civilization, flourishing in the north-western part of the Indian subcontinent, was the largest of the Bronze Age civilizations. With an extent from Shortugai in northern Afghanistan to Daimabad in southern India, and from Sutkagen Dor on the Iranian border to Hulas in Uttar Pradesh, the civilization covered an area in excess of a million square kilometres, and was much larger than both the Nile and Tigris–Euphrates riverine civilizations put together.

The Harappan civilization has left behind astonishing urban complexes. In the words of Kosambi[1], 'Nowhere else was civic organization of such complexity and excellence to be found so carefully planned at so early a date'. The collapse of the civilization after 1900 BCE was dramatic, and urbanism in the subcontinent would reappear a thousand years later in the Gangetic valley. Despite extensive effort, the growth and decline of the Harappan urbanism remains full of unresolved questions[2].

In this communication, we combine topography, hydrology, radiocarbon and archaeological data to perform an extensive spatio-temporal analysis of the growth and decline of urbanism in the greater Indus valley. This reveals interesting spatio-temporal patterns, with important implications for testing hypotheses of the growth and decline of the Harappan civilization. Here, we first describe the data and sources for topography, hydrology and site data. We then provide graphical representations of the spatio-temporal growth and decline, followed by a quantitative analysis of the area distributions of sites.

Our topography data is from the ETOPO2 database from National Geophysical Data Center, USA[3]. In ETOPO2, the Earth's topography is sampled at an angular resolution of 2 arcmin. This corresponds roughly to a distance resolution of 4 km at subcontinental latitude. A subset of the data, covering the region of interest between lat. 19–38°N and long. 62–79°E is retained. The error in the vertical resolution is not more than 200 m, which is negligible at the scale of representation. However, ETOPO2 represents the current topography of the Earth, which may in principle differ from the topography of the Harappan period, especially near coasts. Indeed, there is evidence that the topography of the coastlines in the Indus delta and the Gujarat, in Harappan times, was significantly different from the current topography. While this has no serious implications on the quantitative aspects of our analysis, for comparison, we provide a reconstructed historical coastline in Figure 1. This map is adapted from http://pubweb.cc.u-tokai.ac.jp/indus/english/map.html.

Our source for the hydrology data is HydroSHEDS from the United States Geological Survey[4], which is based on high-resolution elevation data obtained from the NASA Shuttle Radar Topography Mission. HydroSHEDS data supplies detailed hydrological data for the study area including both modern and relic river channels. In particular, palaeo-channels such as the Ghaggar–Hakra are included in the data set. We select a subset of the HydroSHEDS data, including the Indus and the five major rivers of the Punjab, major branches of the Ghaggar–Hakra palaeo-channel system, and the Luni, the Narmada and the Tapi. The earlier caveat regarding the difference between historical and current topography applies to hydrology as well. There have been significant shifts in the hydrology of the region, in particular of the Yamuna and the Ghaggar–Hakra[5]. A careful analysis of the HydroSHEDS data may be able to trace such shifts.

Our source for the radiocarbon and archaeological dates of sites is appendix A of *Indus Age: the Begin-*

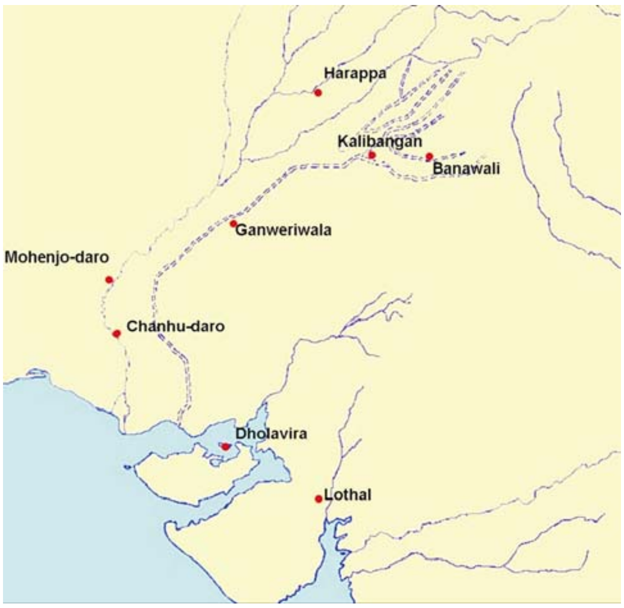

Figure 1. A reconstruction of the coastline during the mature Harappan period. Notice that Dholavira, which is now inland, may have been an island in the mature Harappan period.

nings[6]. It records more than 2000 sites from the greater Indus valley along with their latitude and longitude, area, and archaeological period. Not all of them belong to the Harappan period. Additionally, there are sites with incomplete entries for the latitude, longitude, area and period fields. We have selected 2387 records, corresponding to 1874 sites, which have complete field entries for latitude and longitude, and period. Of these selected records, 1005 have complete field entries for the area. The period assigned to a site in the gazetteer is based on a combination of radiocarbon and archaeological methods. Possehl[6] provides a partial chronology of the archaeological periods, while the remaining has been provided by Shinde (private commun.) to generate a detailed chronology. The greatest source of error in our analysis comes from the uncertainty in both radiocarbon and archaeological dates. In the early Neolithic period, the range of uncertainty can be as large as 500 years (G. L. Possehl, private commun.). In the mature Harappan period, this is typically between 100 and 200 years (G. L. Possehl, private commun.). Thus, the temporal resolution of our analysis also varies, being coarse for the early Neolithic, but becoming more refined in the mature Harappan period. Overall, the uncertainty in the dates needs to be kept in mind while drawing conclusions from this study. A further source of uncertainty is the area assigned to a site. In well-excavated sites like Harappa, a continuous record of the growth and development of the city is available; the earliest layers of Harappa are confined to 10 ha, while the Harappa of the mature period extends to 100 ha[7]. However, such detailed chronological variations of size are not available in a majority of sites. The area therefore in the majority of cases, reflects an estimate made by the excavators and is not always from the earliest layer. Thus, the gradual evolution in size of a site is not contained in the data.

The topographical, hydrological and site data are combined and plotted graphically in Figures 2 and 3 to show the distribution of sites at corresponding times. The earliest and latest dates for these are 7000 and 1000 BCE respectively. The dates chosen in the intervening period correspond to situations where a significant change in the site distributions is observed. Sites are colour coded according to size. An animation sampled at a notional 100-year resolution is available as supplementary material (http: www.youtube.com/watch?v=zpYTGHLZHPU). A detailed description of these plots and key changes at the corresponding times is given here.

In Figure 2 *a*, we show the earliest Neolithic sites of the greater Indus valley. There is little change in this pattern over the 2000-year period covering 7000–5000 BCE. Though archaeologists are of the opinion that this was a period of stasis, it is entirely possible that the apparent lack of development is due to undersampling, or incomplete archaeological excavations, which have not accessed the earliest layers. The site of Mehrgarh, near the Bolan pass, is where the most extensive excavations have been done. This has revealed a continuous habitation through the Neolithic into Harappan times[8]. Mehrgarh is also important because it provides the earliest evidence of wheat and barley farming in the Indian subcontinent[9,10]. It is still unclear whether the domestication of wheat and barley was indigenous, i.e. independent of the domestication which took place in the fertile crescent[11].

The next significant change appears at 4000 BCE, Figure 2 *b*, where in addition to the Baluchistan sites, we now find a cluster of sites in Gujarat in the Jamnagar region. The sites in the Gujarat region appear to have roughly the same distribution of sizes as in Baluchistan, with the exception of Kotada in Jamnagar, Gujarat which has an area of 0.72 km^2. In a remarkable parallel development, a small site appears at Binjour, Ganganagar on what is now the Ghaggar–Hakra palaeo-channel. There is archaeological evidence that Ghaggar–Hakra system had running water in Harappan times. The rapid urbanization along the banks of the Ghaggar–Hakra in the next 300 years would be inconceivable in the absence of copious sources of fresh water. Notably, sites in the Gujarat and Binjour are separated by approximately 800 km, with no Harappan sites in the intervening region. It appears, therefore, that these were independent centres from which urbanization developed.

Rapid development takes place over the next 300 years, and by 3700 BCE (Figure 2 *c*), a large cluster of sites appears along the Ghaggar–Hakra river. A comparison with Binjour at 4000 BCE (Figure 2 *b*) shows that the growth is downstream, indicating perhaps, that the earliest settlers arrived on the Ghaggar–Hakra from further east. It is worthwhile to ask what specific reasons led to independent urbanizations in Gujarat and the Ghaggar–Hakra basin at approximately the same time. This requires further detailed research, though favourable changes in climate and new crops may have been important factors.

In the next 500 years, settlements spread southwards to the lower Indus plains and northwards to the headwaters of the Ghaggar–Hakra. It is difficult to say, on the basis of the spatio-temporal patterns, if the urbanization in the lower Indus was an extension and growth from Baluchistan or if it had contributions from the extensive urbanization of the Ghaggar–Hakra. From the growth patterns, contributions from both these regions appear likely.

By 2500 BCE, Figure 3 *a*, at the start of the mature Harappan period, a dense distribution of sites is found along the Indus, the Ghaggar–Hakra and its headwaters, and in Gujarat. For the next 600 years, this distribution remains unchanged, with approximately 700 sites covering an area of about one million square kilometres. This 600-year period witnesses an overall standardization of the material culture over a vast geographical region. This is evident in the graphemes of the Harappan script, the stylistic design of seals, the weights and measures, and in

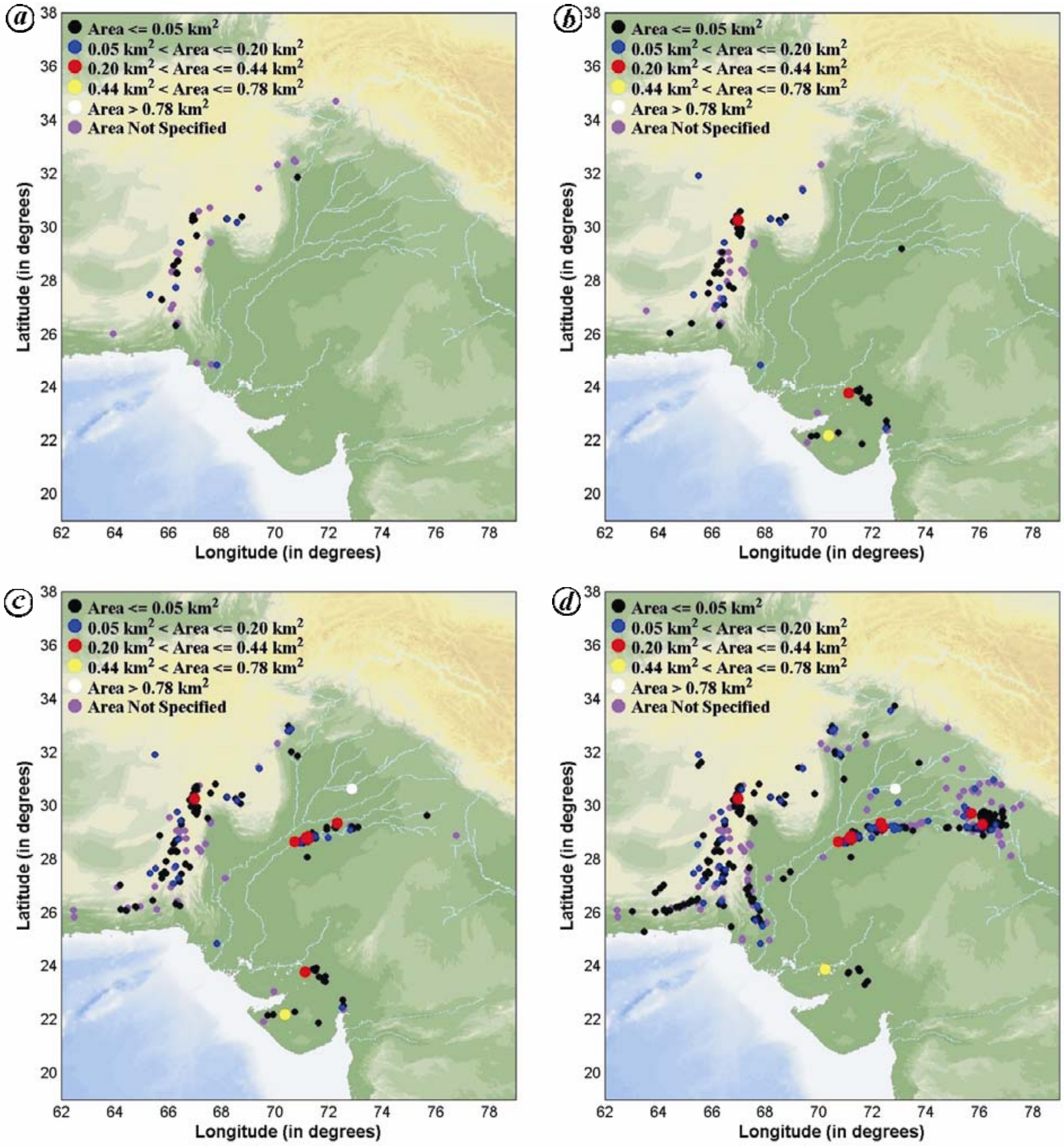

Figure 2. Plots of the distribution of archaeological sites in the greater Indus valley at (***a***) 5000 BCE; (***b***) 4000 BCE; (***c***) 3700 BCE; (***d***) 3200 BCE. Sites are colour coded by area according to the legend. Large area sites are emphasized by increasing their symbol size.

the broad features of urban planning. In the absence of a strong imperial centre, as in Egypt or Mesopotamia, it remains unclear exactly what political and economic forces were at work in producing this standardization which was so characteristic of the mature Harappan period. There is a broad distribution in areas (and consequently populations) of sites during the mature Harappan period. A quantitative analysis of the distribution of areas shows, quite remarkably, a Zipf distribution, characteristic of modern urban agglomerations. The number density n of sites of area a and a best-fit curve to the Zipf form $\log(n) = \alpha - \beta\log(a)$ is plotted in Figure 4. Our best-fit parameters are $\alpha = 231.9$, $\beta = 1.326$, while corresponding values for a modern urban conglomeration are $\alpha = 10.53$, $\beta = 1.005$ (ref. 12). It is of interest to further explore the implications of these correspondences.

The decline phase of the urbanization begins around 1900 BCE (Figure 3 *b*), when the number of sites along the mid-Ghaggar–Hakra reduces, while the number of sites along the Ghaggar–Hakra headwaters increases.

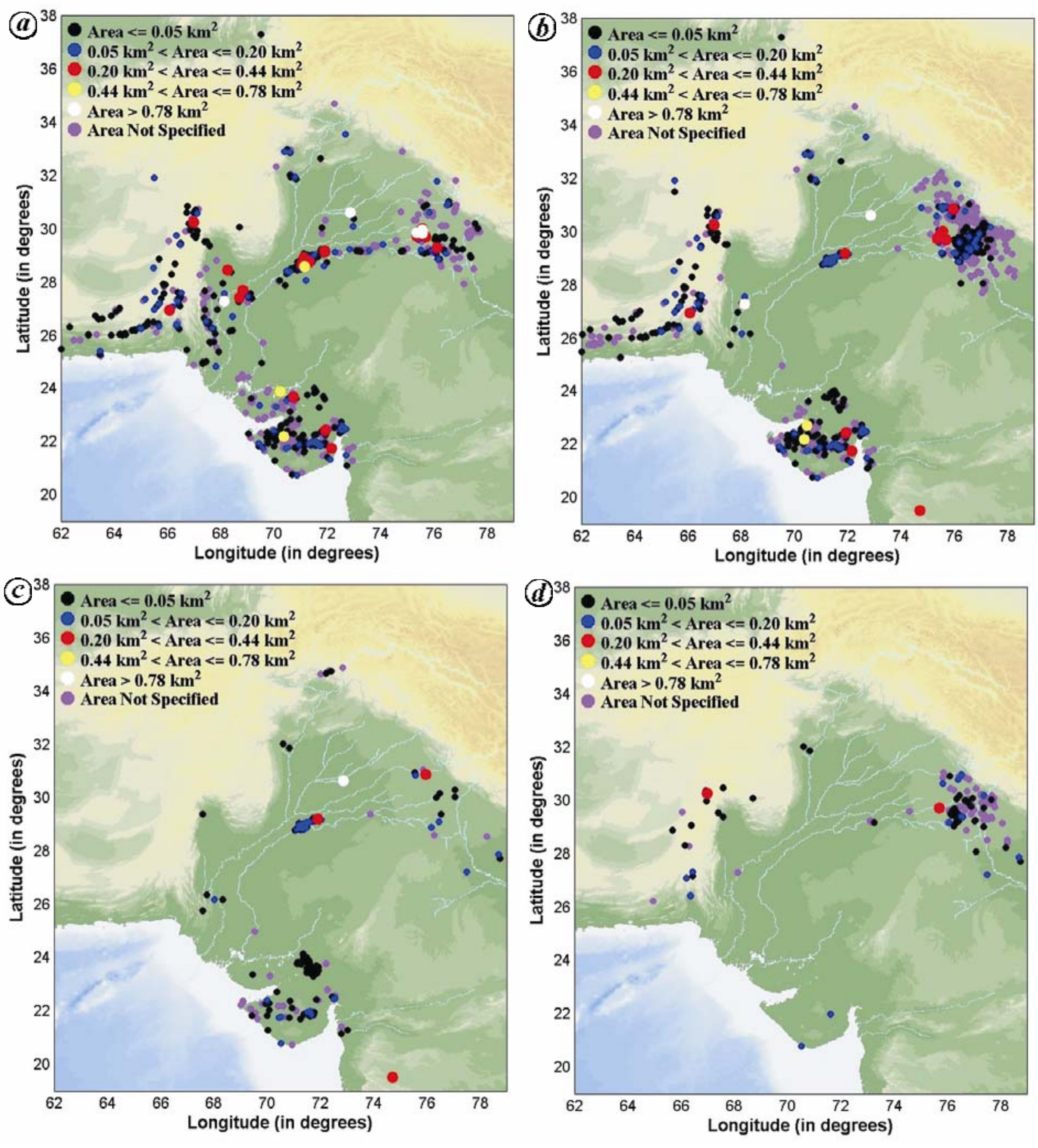

Figure 3. Plots of the distribution of archaeological sites in the greater Indus valley at (***a***) 2500 BCE; (***b***) 1900 BCE; (***c***) 1500 BCE; (***d***) 1000 BCE. Sites are colour coded by area according to the legend. Large area sites are emphasized by increasing their symbol size.

Significantly, large sites give way to more numerous smaller sites, indicating a breakdown in urbanism. Further, the shift in sites from the Ghaggar–Hakra to its headwaters may point to habitat-tracking as the main cause underlying the large-scale displacements. Sites in the lower Indus also reduce in number, but unlike the Ghaggar–Hakra region, no compensatory increase occurs in nearby regions. This may indicate that a habitat-tracking option was not available in the lower Indus and, therefore, the decay of urban organization was of a more permanent nature. Remarkably, though, sites in the Gujarat region appear not to be affected by the decline in the lower Indus and Ghaggar–Hakra regions. This may indicate that factors responsible for the decline had a smaller effect in the Gujarat than elsewhere in the Harappan region. A quantitative comparison of the changes in the site distributions at the onset of the decline phase is provided in Figure 5.

Table 1. Listing of time periods[5,6]

Sl. no.	Period name	Start time	End rime	Sl. no.	Period name	Start time	End time
1	Kili Ghul Mohammad	7000 BCE	5000 BCE	46	Cemetery H	1900 BCE	1500 BCE
2	Early Kulli	7000 BCE	3500 BCE	47	Jhangar	1900 BCE	1500 BCE
3	Burj Basket-marked	5000 BCE	4300 BCE	48	Post-urban Harappan (Bara)	1900 BCE	1500 BCE
4	Togau	4300 BCE	3800 BCE	49	Post-urban Harappan (OCP)	1900 BCE	1500 BCE
5	Anarta blade making	4000 BCE	3500 BCE	50	Anarta–Rangpur IIC	1800 BCE	1500 BCE
6	Anarta with Microliths	4000 BCE	3500 BCE	51	Black and red ware	1800 BCE	1500 BCE
7	Anarta (pre-Harappan)	4000 BCE	3500 BCE	52	Late Sorath Harappan–Malwa	1800 BCE	1500 BCE
8	Microlith blade making	4000 BCE	3500 BCE	53	Microliths–Rangpur IIC	1800 BCE	1500 BCE
9	Microliths	4000 BCE	3500 BCE	54	Pirak III	1800 BCE	700 BCE
10	Hakra wares	3800 BCE	3200 BCE	55	Malwa	1700 BCE	1300 BCE
11	Kechi Beg	3800 BCE	3200 BCE	56	Gandhara Graves	1700 BCE	600 BCE
12	Hakra–Ravi	3700 BCE	2800 BCE	57	Swat Proto-Historic	1650 BCE	1300 BCE
13	Anarta Chalcolithic	3500 BCE	3000 BCE	58	Lustrous red ware	1600 BCE	1300 BCE
14	Hakra wares (overlap)	3200 BCE	3100 BCE	59	Anarta–Lustrous red ware	1500 BCE	1200 BCE
15	Nal	3200 BCE	2800 BCE	60	Proto-PGW	1500 BCE	1200 BCE
16	Amri-Nal	3200 BCE	2600 BCE	61	Jorwe	1500 BCE	1100 BCE
17	Amri-Nal burial pottery	3200 BCE	2600 BCE	62	Post-urban/PGW	1500 BCE	1000 BCE
18	Anjira	3200 BCE	2600 BCE	63	Post-urban/PGW overlap	1500 BCE	1000 BCE
19	Damb Sadaat	3200 BCE	2600 BCE	64	OCP/Post-urban Harappan	1300 BCE	1100 BCE
20	Kot Diji	3200 BCE	2600 BCE	65	Iron age	1200 BCE	1000 BCE
21	Sothi–Siswal	3200 BCE	2600 BCE	66	Prabhas (Rojdi B-C)	1200 BCE	1000 BCE
22	Anarta	3000 BCE	2600 BCE	67	OCP	1100 BCE	700 BCE
23	Anarta-Harappan	3000 BCE	2600 BCE	68	PGW	1100 BCE	500 BCE
24	Shahi Tump	3000 BCE	2600 BCE	69	PGW and NBP	700 BCE	500 BCE
25	Pre-Prabhas	2900 BCE	2600 BCE	70	NBP	700 BCE	200 BCE
26	Early to mature Harappan	2600 BCE	2500 BCE	71	Buddhist	600 BCE	400 CE
27	Mature Harappan	2500 BCE	2000 BCE	72	Early Historic	600 BCE	600 CE
28	Rangpur IIB	2500 BCE	2000 BCE	73	Partho-Sassanian	500 BCE	200 BCE
29	Kulli	2500 BCE	1900 BCE	74	Red polished ware	200 BCE	200 CE
30	Late Kot Diji	2500 BCE	1900 BCE	75	Kushan	200 BCE	300 CE
31	Quetta	2500 BCE	1900 BCE	76	Kushan–Rang Mahal	200 BCE	300 CE
32	Sorath Harappan	2500 BCE	1900 BCE	77	Rang Mahal	200 CE	500 CE
33	Anarta–Rangpur IIB	2400 BCE	1800 BCE	78	Late Historic	700 CE	800 CE
34	Savalda	2200 BCE	2000 BCE	79	Early Historic–Medieval	700 CE	900 CE
35	Dasht	2200 BCE	1800 BCE	80	Early Medieval	900 CE	1300 CE
36	Sorath or Late sorath Harappan	2200 BCE	1800 BCE	81	Early Islamic	1100 CE	1300 CE
37	Rangpur IIB-C	2100 BCE	1800 BCE	82	Medieval	1100 CE	1700 CE
38	Daimabad culture	2000 BCE	1600 BCE	83	Medieval Cemetery	1100 CE	1700 CE
39	Chalcolithic blade manufacturing	2000 BCE	1500 BCE	84	Islamic	1300 CE	1600 CE
40	Copper Hoard	2000 BCE	1500 BCE	85	Islamic Kulli	1300 CE	1600 CE
41	Jhukar	1900 BCE	1800 BCE	86	Islamic–British	1600 CE	1700 CE
42	Anarta–Rangpur IIB-C	1900 BCE	1700 BCE	87	Late Medieval	1600 CE	1800 CE
43	Post-urban Harappan	1900 BCE	1700 BCE	88	British	1700 CE	1950 CE
44	Rangpur IIC	1900 BCE	1700 BCE	89	Modern	1850 CE	2008 CE
45	Late Sorath Harappan	1900 BCE	1600 BCE	90	Recent	1850 CE	2008 CE

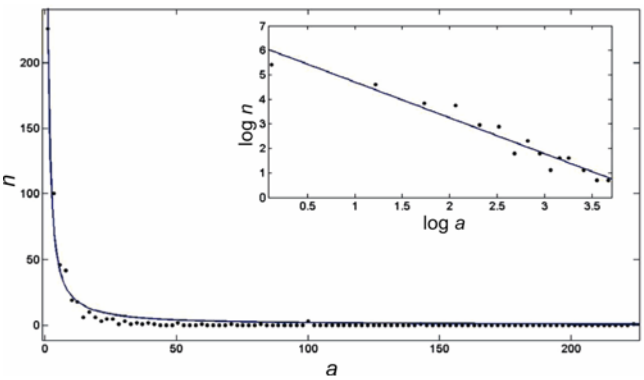

Figure 4. Frequency distribution of the area of sites. The number density n of sites with area a is plotted alongside a best-fit to the Zipf form $n = \beta a^{-\alpha}$. In the inset, the same data is plotted in double logarithmic axes. The best-fit values are $\alpha = 231.9$, $\beta = 1.326$.

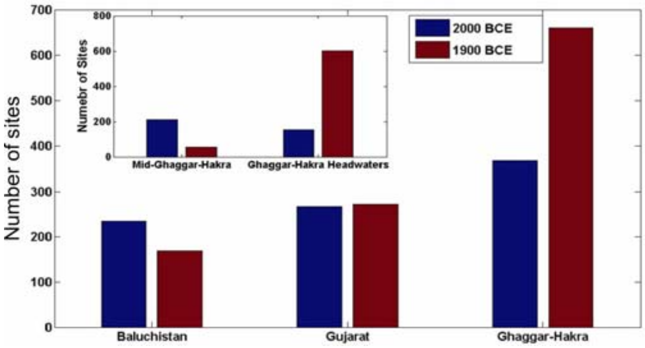

Figure 5. Histogram comparing the site distribution in Baluchistan, Gujarat and the Ghaggar–Hakra valley at the onset of the decline phase. The greatest differential change is seen in the Ghaggar–Hakra region. The increase in site numbers is due to large sites being replaced by numerous smaller sites. The inset plot shows the distribution of sites within the Ghaggar–Hakra valley. A clear transfer of habitation to the upper reaches of the Ghaggar–Hakra is discernible.

By 1500 BCE the collapse of urbanism is nearly complete with very few sites in the Indus and Ghaggar–Hakra regions (Figure 3 *c*). Tracking the development of the decay from 1900 BCE, the most rapid reduction in the number of sites occurs in the lower Indus, followed by the Ghaggar–Hakra region. The Gujarat region is comparatively more resilient, and shows a slow and gradual decline over a period of 400 years.

By 1000 BCE the remaining Gujarat sites are also abandoned, and new sites begin developing in the Gangetic plain, which form the basis of the second urbanization around 600 BCE (Figure 3 *d*).

The picture that emerges from these plots is a complex, and spatially heterogeneous pattern of growth and decline of urban settlements in the greater Indus region. Several mechanisms may have been at work to produce such heterogeneities, including the variation in climate, soil, irrigation and domesticated crops. Based on the patterns revealed by our study, it may now be possible to test competing hypotheses for the growth and decline of the Indus urbanization within a Bayesian inferential framework. This shall be pursued in the future.

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