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Counter-intuitive influence of Himalayan river morphodynamics on Indus Civilisation urban settlements

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Urbanism in the Bronze-age Indus Civilisation (~4.6–3.9 thousand years before the present, ka) has been linked to water resources provided by large Himalayan river systems, although the largest concentrations of urban-scale Indus settlements are located far from extant Himalayan rivers. Here we analyse the sedimentary architecture, chronology and provenance of a major palaeochannel associated with many of these settlements. We show that the palaeochannel is a former course of the Sutlej River, the third largest of the present-day Himalayan rivers. Using optically stimulated luminescence dating of sand grains, we demonstrate that flow of the Sutlej in this course terminated considerably earlier than Indus occupation, with diversion to its present course complete shortly after ~8 ka. Indus urban settlements thus developed along an abandoned river valley rather than an active Himalayan river. Confinement of the Sutlej to its present incised course after ~8 ka likely reduced its propensity to re-route frequently thus enabling long-term stability for Indus settlements sited along the relict palaeochannel.

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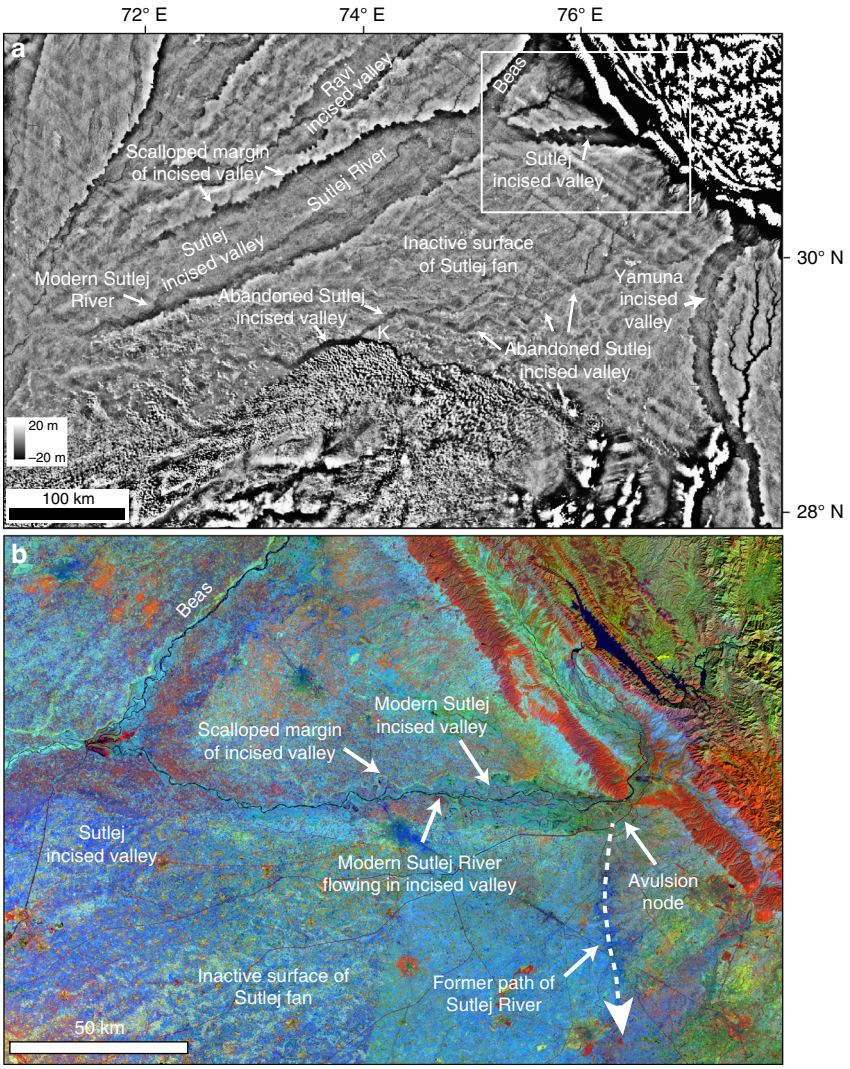

Fig. 10 Topography of Sutlej–Yamuna plains showing modern Himalayan rivers occupy incised valleys. **a** Detrended relative elevation map, derived from SRTM 30 m DEM (2014 release), showing courses of the modern Sutlej, Beas and Yamuna rivers confined to regionally extensive incised valleys eroded into alluvial deposits of the Indo-Gangetic basin. Confinement prevents the rivers from readily avulsing across older fluvial fan surfaces. White box indicates area of detailed image in **b**. **b** Detail from Landsat 5 TM colour composite mosaic in Fig. 2 showing modern Sutlej incised valley near its outlet at Himalayan mountain front. Inferred palaeo-Sutlej course that joins Ghaggar-Hakra palaeochannel, a former Sutlej incised valley, is indicated, as is the likely river avulsion node

[4], although inadequate chronologies of both fluvial deposits and archaeological sites has limited the integration of fluvial and archaeological records. Recent studies in the desert Nile have shown that alluvial dynamics were important in determining whether climate-modulated fluctuations in river flow represented opportunities or hazards for Bronze-age farming communities[76]. It is clear that societal response to environmental change is not as straightforward as postulated in many studies. In the case of the Indus Civilisation it has been widely assumed that ancient urban-scale settlements developed adjacent to large rivers, which served as water sources. While this is demonstrably true for parts of the Indus geographical sphere[19, 21], this assumption has led to the belief that the largest concentration of urban-scale Indus settlements, located on the drainage divide between the Yamuna and Sutlej rivers in northwestern India and in Cholistan, Pakistan, were contemporaneous with a Himalayan-sourced river that flowed along the trace of the Ghaggar–Hakra palaeochannel. Extension of this argument led to the supposition that diversion or drying up of this major river triggered the decline and abandonment of these urban sites from ~4.0–3.9 ka B.P.[14]. These ideas have dominated the discourse on environmental dynamics and Indus societal response during Indus times[50].

Our OSL-derived chronologies firmly establish that a major Himalayan river was not contemporaneous with Indus settlements in the Ghaggar–Hakra region and did not sustain the Indus Civilisation in this region. This finding resolves a question that has been debated for well over a hundred years. Our analysis shows that the Ghaggar–Hakra palaeochannel is a former course of the Himalayan Sutlej River that formed and occupied an incised valley from at least ~23 ka (Fig. 10a). Initial abandonment of this incised valley by the Sutlej River commenced after ~15 ka, with complete avulsion to its present course shortly after ~8 ka. This involved a lateral shift of the Sutlej River by up to 150 km, with the avulsion node located close to the Sutlej exit at the Himalayan front (Fig. 10). While we cannot identify the root cause of this avulsion, its timing after ~8 ka corresponds with the onset of a long phase of decline in the strength of the Indian Summer Monsoon (ISM)[77, 78] that may indicate a possible climatic control on river reorganisation. However, it is important to

point out that avulsion is an autogenic mechanism and need not mark a response to an external event.

Our study sheds new light on the role of river dynamics on early urbanisation. We find that the locus for the abundant Indus Civilisation urban settlements along the Ghaggar–Hakra palaeochannel was the relict, underfilled topography of a recently abandoned valley of the Himalayan Sutlej River rather than an active Himalayan river. We suggest that this abandoned incised valley was an ideal site for urban development because of its relative stability compared to Himalayan river channel belts that regularly experience devastating floods and lateral channel migration. It is also worth noting that many large Himalayan rivers are typically characterised by high avulsion frequencies, with rivers commonly revisiting past courses. For example, the Kosi River in the eastern Ganges basin shows an average avulsion frequency of 24 years[79]. However, in the western Ganges basin, rivers such as the Sutlej and the Yamuna flow in incised valleys that are deeply entrenched in abandoned alluvial plains (Fig. 10) [52, 80, 81], and form regionally extensive sediment routing corridors. We suggest that confinement to incised valleys reduced the propensity for these rivers to frequently re-route. Since complete avulsion of the Sutlej River to its present course shortly after ~8 ka, the Sutlej has remained trapped in an incised valley and has not revisited its former Ghaggar–Hakra course. This has provided environmental stability within the Ghaggar–Hakra palaeovalley, a factor that may have helped to enable the long-term development of Indus urban settlements.

Following avulsion of the palaeo-Sutlej to its present course, the relict incised valley became partially infilled by very fine-grained sediments that we interpret as deposition from ephemeral monsoon-fed rivers derived from the Himalayan foothills, likely the equivalent of the modern Ghaggar River and its tributaries. Similar, very fine-grained infill was also documented by Saini et al.[45, 46] along a section of the Ghaggar–Hakra palaeochannel. Thus, despite the diversion of the Sutlej, some fluvial flow and deposition of fine sediment continued in the topographic low formed by the relict valley. Our OSL dates from the upper part of the incised valley fill (core GS10) show that up to 6 m of fine-grained fluvial sediment were deposited from ~12.5 to ~5–6 ka, with only ~2 m of red clays above this section. The higher rate of deposition in the early Holocene corresponds to the interval of strengthened Holocene ISM from 10–7 ka[78]. The decrease in fluvial sedimentation after ~5 ka is likely due to the decrease in monsoon intensity documented after ~ 6 ka[78]. The fining-up character of the Holocene succession in our cores with very fine-grained sands and silts showing upward transition to silty clay suggests a progressive decrease in fluvial competence and decline in fluvial activity, which mirrors trends seen in the regional climate records of ISM weakening[78, 82, 83].

The persistence of fine-grained fluvial sedimentation in the Ghaggar–Hakra incised valley during the mid-Holocene demonstrates that Indus urban settlements in the region were likely sustained by monsoon-fed fluvial activity. However, the Indus urban settlements were occupied at a time of strongly-reduced fluvial activity compared with the Himalayan-fed river system before ~15–9 ka or the moderate activity in the early Holocene. It thus seems improbable that Indus settlements flourished due to 'perennial' monsoon-fed river flow as proposed by Giosan et al.[39]. Likewise, our results show clearly that avulsion of the Himalayan-fed Sutlej, and decline in monsoon-fed fluvial activity within the Ghaggar–Hakra palaeochannel, predate both the establishment and decline of Indus urban settlements in the region, ruling out a causal link. Giosan et al.[39]suggested that decline in monsoonal rivers due to weakening of the ISM was responsible for this transformation of the Indus urban system. While independent climate records provide strong evidence for widespread weakening of the ISM across large parts of India at ~ ~ 4.2–4.0 ka[83], and our cores indicate a marked decrease in sedimentation rate after ~5 ka, current fluvial chronologies lack the resolution necessary to draw robust conclusions regarding the influence of climate-modulated river activity on the decline of the Indus urban system. Future development of high-resolution chronologies for late Holocene fluvial records in this region may permit testing of climatic influence on river flow and its possible relationship to decline of Indus urban settlements.

A significant unresolved issue is that not all urban settlements in the region are necessarily co-located with the Ghaggar–Hakra palaeochannel[84]. The largest Indus site in the region, Rakhigarhi, widely considered to be of the scale of an Indus city[14, 16, 85], is situated at least 50 km from the Ghaggar–Hakra palaeochannel. Although its location has been linked to another abandoned river system, the Drishadvati[85], in situ data are necessary to determine the existence and timing of such river activity before drawing inferences on how such sites were sustained.

In conclusion, our results firmly rule out the existence of a Himalayan-fed river that nourished Indus Civilisation settlements along the Ghaggar–Hakra palaeochannel. Instead, the relict Sutlej valley acted to focus monsoon-fed seasonal river flow as evidenced by very fine-grained sediments in the upper part of the valley-fill record. This and the potential to pond flood waters in the topographic depression[38] formed by the valley likely offered favourable conditions that led Indus populations to preferentially settle along the incised palaeovalley. We find that river dynamics controlled the distribution of Indus sites in the region, but in the opposite sense to that usually assumed: it was the departure of the river, rather than its arrival, that triggered the growth of Indus urban settlements here. We posit that a stable abandoned valley, still able to serve as a water source but without the risk of devastating floods, is a viable alternative model for how rivers can nucleate the development of ancient urban settlements.

Data availability. The data that support the findings of this study are included in this published article (and its Supplementary Information files) or are available from the corresponding author upon reasonable request.

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