Research

Water supply and history: Harappa and the Beas regional survey

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Introducing the methods of archaeoclimatology, the authors measure the relative locus of the monsoons, the intensity of winter rains and the volume of water in the rivers in the Upper Indus, in the region of Harappa. They also note the adoption of a multi-cropping agricultural system as a possible strategy designed to adjust to changing conditions over time. They find that around 3500 BC the volume of water in the rivers increases, and the rivers flood, implying annual soil refreshment and the consequent development of agriculture. By contrast, from around 2100 BC the river flow begins to fall while the winter rains increase. This time-bracket correlates nicely with the brief flourishing of Harappa. The locally derived evidence from Harappa combined with the Beas survey data provide a model for understanding the abandonment of settlements in the Upper Indus and possibly the wider civilisation.

Keywords: Indus, Harappa, agriculture, climate, river flow

Introduction

The Indus (or Harappan) culture is one of the world's great riverine civilisations. Its highest density of population settled along two major river systems, the Indus and the Ghaggar-Hakra. The Indus, one of the great rivers of Asia, originates in the Himalayas and flows at present through a vast dry zone before emptying into the Arabian Sea. Its fertile floodplains have sustained populations in this region for millennia. At its upper reaches the Indus system consists of the Indus and five other rivers, the Jhelum, the Chenab, the Ravi, the Beas and the Sutlej. These drainages converge near the modern city of Multan forming the trunk stream of the Lower Indus. The Ghaggar-Hakra is to the east on the border between Pakistan and India. Though the Ghaggar-Hakra was once dynamic, it ceased to supply water to this region at some time in the past.

The focus of this paper is on the history of the river and its interaction with the local climate and their impacts on agricultural systems in the Upper Indus. Specifically, the study addresses the environmental conditions under which settlement and agriculture developed in the Upper Indus, in the area of the city of Harappa and along the nearby Beas river, where 18 Indus settlements have been discovered (Wright *et al.* 2002; 2005a; 2005b). We

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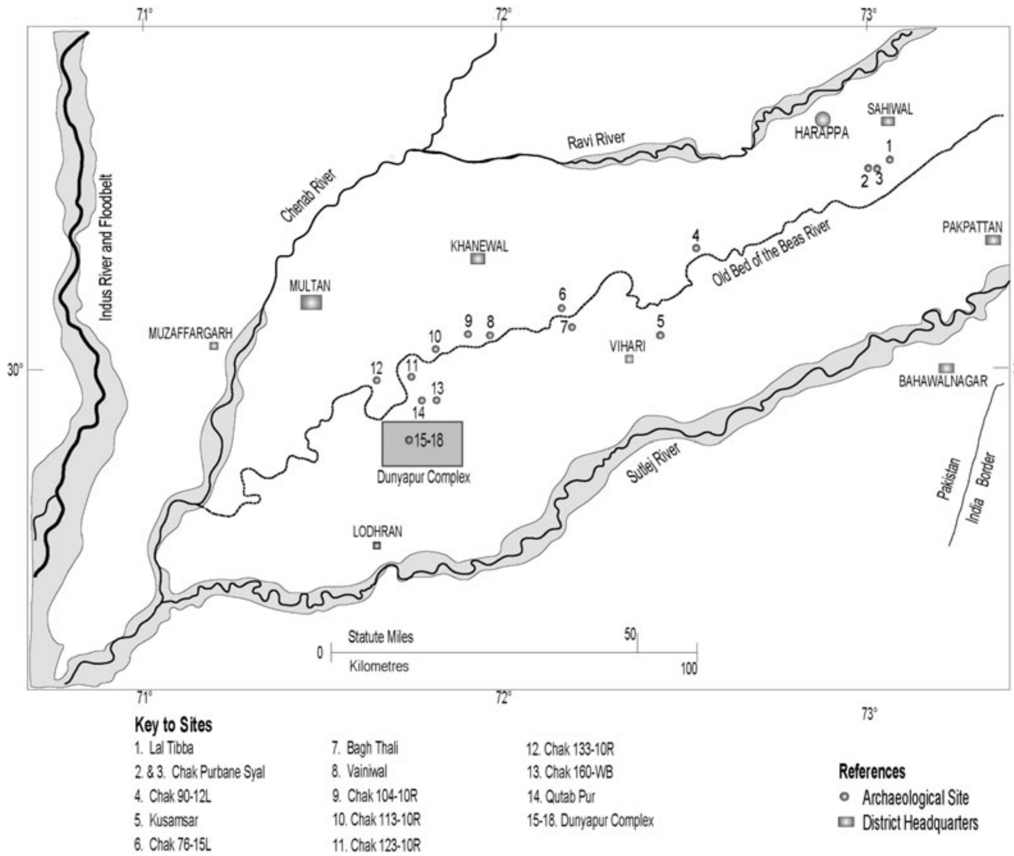

Figure 1. Site locations of Harappa and the Beas regional survey.

introduce a new, powerful tool for exploring the climatic environment of ancient cultures called *Archaeoclimatology*, a high-resolution, site-specific climate model applicable almost anywhere.

Background to settlement of the Upper Indus

The earliest evidence for settlement of the Upper Indus dates to 3300 BC when a small village developed at Harappa (the Ravi/Hakra phase). Along the Beas, three of its 18 settlements (Figure 1) were assigned to this early period (sites labelled 4, 8 and one in the settlement complex 15-18). In the following Early Harappan (2800-2600 BC), Harappa grew into a small town while 11 new sites were founded along the Beas. The three Ravi/Hakra sites continued to be occupied. In addition, there are new settlements (labelled 1, 5, 9, 10, 11, 12, 13, 14 and three at 15-18). By 2600 BC (Mature, Urban Harappan) Harappa had grown to a major city (approximately 150ha) and the Beas settlements numbered 18, one of which was 14ha, four were between 5-10ha and the others were <5ha. Beginning at approximately 1900 BC, there were signs of deterioration in Harappa's infrastructure, although it was not abandoned until possibly as late as 1300 BC. By then, only four Beas sites (2/3, 6, 7 and 8) were sustained, but they were vastly diminished in size and eventually abandoned.

The Harappan economy was based upon agriculture, pastoralism and craft production. Its major crops included cereal grasses, predominantly wheat and barley, as well as millets, peas, lentils, linseed, possibly cotton, dates, jujube and grapes. The diversity of crops present during the earliest occupations at Harappa indicates that the local population developed a multi-cropping system. Wheat and barley were grown in the winter months and millets, a drought resistant crop, and some fruits and cotton in the summer. By 2600 BC an increasing proportion of cultivated plants were made up of the summer crops, although wheat and barley continued to be *'the mainstays of the agricultural system'* (Weber 2003: 180; see also Fuller & Madella 2002; Madella & Fuller 2006). The animals exploited were predominantly domesticated sheep, goat and cattle. Signatures on animal bone indicate that zebu cattle were kept for meat as well as for ploughing (Miller 2003). Water buffalo are depicted on seals and are present in small quantities in the faunal assemblages at Harappa, but there is no secure evidence for their domestication there (Patel & Meadow 1998). Beas settlements extended the ecological niche by providing agricultural and pastoral resources. Craft products included objects produced from plant and animal fibres, as well as stone and clay.

Climate change and the Indus civilisation

The model presented in this paper deals with a problem central to the onset, florescence and abandonment of the settlements in the Upper Indus. Its implications for the greater Indus, which includes the Ghaggar-Hakra system, are not addressed in this study. As discussed, the evidence from Harappa and the Beas sites indicates that Indus farmers experimented with a number of different crops and implemented cropping patterns that changed over time. Changes of this sort can be the result of various considerations, including food choice or agricultural strategies in response to shifting environmental conditions. The two significant factors with respect to the latter were local precipitation levels and water discharge along the valleys on which the settlements were located.

Previous discussions of climate change by archaeologists have involved various proxy measures, not all from the Harappa area: methods used on the Ghaggar-Hakra include sedimentation and soil formation (Courty 1995), and settlement shifts (Mughal 1997; Pande 1977; Wilhelmy 1969), while on the Lower Indus researchers used landsat and aerial photographic mapping (Flam 1993; 1999) and geomorphological rates of sedimentation, stream slope and channel displacements (Harvey & Flam 1993; Jorgensen *et al.* 1993). Additional studies implicating climate change include analyses of charcoal and pollen species from archaeological sites in northern Baluchistan (at Mehrgarh) and southern Baluchistan (Makran), where two local ecosystems have been identified, a riverine forest and shrub or woodland (Tengberg & Thiébault 2003; Thiébault 1988a; 1988b; 1989; 1992). Pollen studies conducted in Las Bela complement the wood analyses (McKean 1983). Other data are too distant to be representative of the Harappa area. They include sediments excavated from lake beds in the Thar Desert (Enzel *et al.* 1999; Singh *et al.* 1974; 1990), analysis of pollen from alpine peat collected in the Himalayas (Phadtare 2000), inferences based on relative thicknesses of turbidite varves from coastal cores (Von Rad *et al.* 1999) and on combinations of these and other regional-scale proxies (Madella & Fuller 2006).

Interpretations of these data are inconsistent. Cores from the Thar Desert, peat deposits in the Himalayas and ocean sediments suggest that an onset of aridity was coincident with the decline of the Indus with maximum winter rains during the Indus periods followed by decreasing precipitation. Interpretations of the turbidite varves suggest there were fluctuations in precipitation showing peaks of monsoon intensity and decreasing force after 4000-3500 yr BP, calibrated to *c*. 2000-1750 cal BC; after 1750 BC there was continued instability until 200 BC when precipitation was at its minimum. A recent synthesis of the climatic implications of the South Asian Holocene landscape record has been assembled by Schuldenrein (2002) and Madella and Fuller (2006).

The climatic controls

There are two separate and distinct sources of rainfall in the Indus watershed: the winter rains associated with storms that originate in the Mediterranean and pass through the fertile crescent, then along the Makran and Las Bela coasts and terminate in the north-west of the Indian subcontinent; and the summer rains associated with the 'Summer Monsoon', which in this area are initiated by the seasonal northward movement of the Intertropical Convergence (ITC). The two elements of the annual rainfall pattern are only connected by hemispheric conditions. The number of winter storms is related to the winter circulation patterns attendant to eastern Mediterranean cyclonic storms. The monsoon on the other hand is related entirely to the broad scale temperature patterns that produce a far northward movement of the ITC. Very broadly, reference is made to the maximum temperature occurrence over the Asian continent.

Most of the winter precipitation from the westerly storms falls in the north of the Indus area, in the foothills and western Himalayas proper. The rainfall regime associated with the ITC is more complicated. Ahead of the advancing edge of the moist southern-hemisphere air behind the ITC there is essentially no rain. Then with the passage of the ITC there is a zone of heavy rain, traditionally called the 'burst' of the monsoon. Farther behind the ITC, the precipitation is in the form of frequent light showers interspersed often with sunshine periods- but almost always damp. This is usually not associated with deep convection (cumulonimbus, or thunderstorms) but with clouds with tops at only 3 to 4km elevation according to pilots who fly over the area. The well-known pre-monsoon occasional shower in the region can be shown to be associated with air moistened in crossing the Arabian Sea from Africa rather than true southern hemisphere monsoon air. It has been known for at least a century, however, that if the monsoon moves rapidly and too far north, there will be too little rainfall over the sub-continent proper. That will become evident in this study.

History of the ITC

Archaeoclimatology or Macrophysical Climate Modelling is, in essence, a top-down modelling approach predicated on orbital forcing, variations in atmospheric transparency,

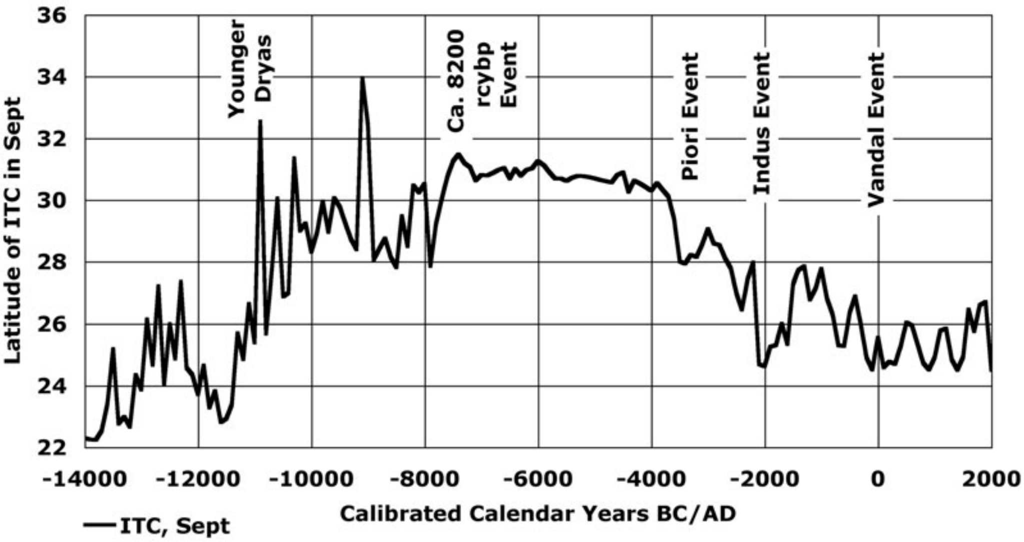

Figure 2. Modelled Intertropical Convergence history 80° E.

and the principles of synoptic (large-scale) climatology (Bryson 2005; Bryson & DeWall 2007a). Numerous publications have demonstrated the utility of the model for archaeological questions, as well as the accuracy of the model when compared to existing field data and climate proxies (Bryson & Bryson 1997; 2000; Bryson & DeWall 2007b; Ruter *et al*. 2004). Using archaeoclimatic methods (Bryson 2005), the latitude of the ITC at 80°E may be calculated as a function of the location of the subtropical anticyclones and the jet stream. Figure 2 is a plot of the changes in mean September latitude over the past 16 000 years.

As expected, the position of the ITC roughly follows the hemispheric temperature history or the precession of the equinox, but with modification. In the early Holocene with maximum summer hemispheric temperatures but still very cold winters, the contrast was great between the seasons and the ITC moved rapidly far north in spring and early summer. Later in the Holocene as the summer radiation diminished and the winter radiation increased, the contrast was diminished and the ITC did not move as far north or stay there as long.

The periods of suppression of the northward movement at roughly 9500 to 7500 BC, 3600 to 3100 BC, 2100 to 1500 BC, and 500 BC to AD 500 are the result of global bursts of volcanic activity which attenuate the incoming radiation and show up globally in reduced temperatures. These are known, in order, as the Cochrane (*c*. 8200 rcybp), the Piori, the Indus, and the Vandal Events, to use non-descriptive terminology. The type locality for the Indus Event is Lunkaransar lake near Bikaner, Rajasthan where a significant climatic event was found to have occurred in what was then part of the Indus culture area (Bryson 1994; 1997; Staubwasser *et al*. 2003). Type locality here means the place for which the event was first described.

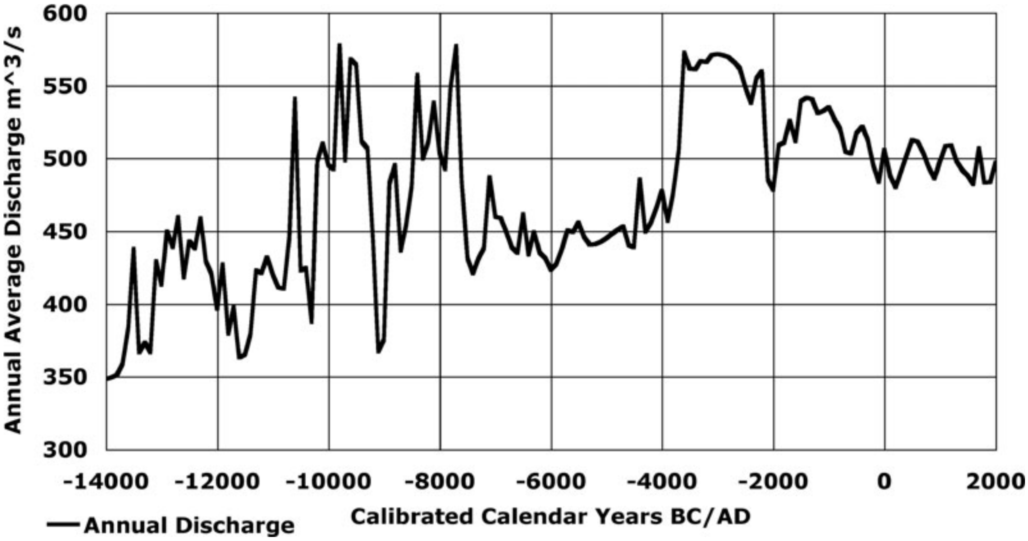

Figure 3. Modelled annual discharge history of the Beas river at Mandi plain, Pakistan.

The river discharge consequences of the ITC history

Figure 2 suggests that as Asia warmed erratically at the Pleistocene-Holocene transition (*c*. 14 000 BC), the ITC moved erratically north. The erratic behaviour is what one might expect because of the observed intense bursts of volcanic activity at that time. In turn this transition might be expected to enhance volcanic activity because of the crustal deformation associated with deglaciation. The discharge of the Beas river, as modelled on the basis of the ITC position, is shown in Figure 3. The values shown are century averages, however, and it is emphasised that there are yearly and decadal variations about this average. Apparently, about 7500 BC the ITC had moved too far north and the precipitation on the Beas watershed no longer had the prolonged heavy rainfall associated with the 'burst' of the monsoon. The discharge settled at around $450m^3$/sec until about 3600 BC when it abruptly increased to about $570m^3$/sec, a 27 per cent increase in a very short period. This new, high level of discharge remained almost unchanged for almost 1500 years. The Lower Indus, as shown by the discharge at Mandi shows an increase of over 300 per cent at the same time! (Bryson & DeWall 2007a).

The local climatic and agricultural effects

Harappa itself, quite a distance south of the Himalayas, and drier than the foothills, also shows a reaction to the movement of the ITC. This shift is shown in Figure 4, which suggests a 600-year period of reduced rainfall after 2100 BC. It appears that the monsoon rains did not reliably return after that time, but there was the appearance of more winter rains. If this sequence of events is correct, one must conclude that there must have been a significant change in subsistence practices.

Consider the sequence of events suggested by this model. For millennia, the land was marginal for rain-fed agriculture and the rivers were typically contained within their

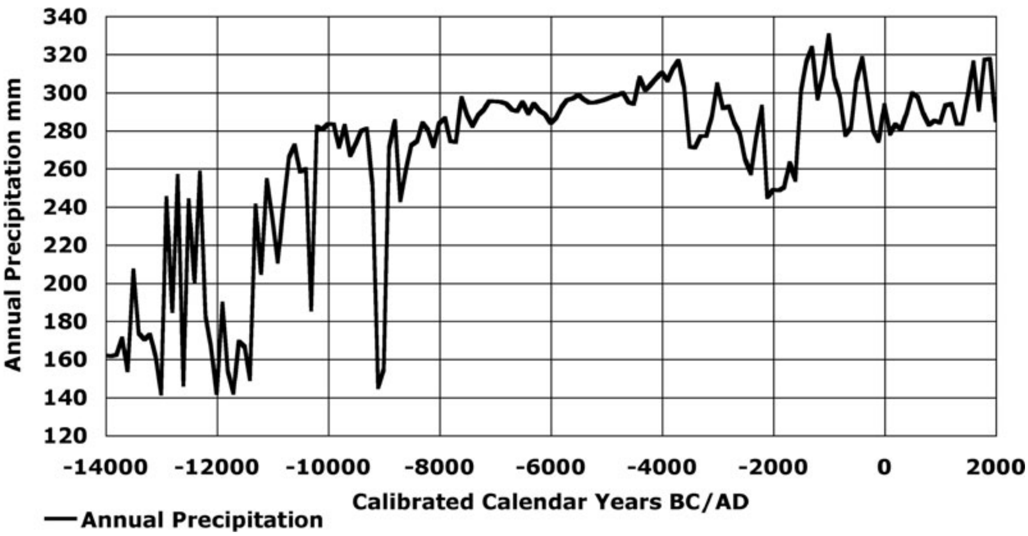

Figure 4. Modelled annual precipitation history at Sahiwal, Pakistan (near Harappa).

channels. They were low-flow streams which probably supported a sparse riparian scrubland. Suddenly about 3600 BC there was a dramatic change to higher energy stream flow with much more discharge. Increased stream dynamism persisted for 1500 years (*c*. 2100 BC). If anything, precipitation decreased locally. These hydrographic changes probably promoted the development of riverine agriculture. This combination over a millennium and a half requires the development of agriculture based on the over-bank flooding of the river.

After 1500 years of stability, there came an unexpected agricultural crisis. About 4100 years ago, the rivers failed to deliver the usual abundance of water, and the volume of rains, though meagre, decreased also. After so long, the memory of different, drier, times had probably been lost also. This withdrawal of the monsoon wet edge from the Harappa area means that the region of heavier monsoon rains should have been located farther south. This was shown by Khadkikar *et al.* (2004) who demonstrated the probability of floods at Lothal at that time.

There was another change. The winters had been very dry, but when after centuries, there was a resurgence in precipitation, and an increase in winter rain, without, however, restoring the river flow (Figure 5). The long stable climatic period during which the Indus Culture developed and flourished appears to have been unique in the last 14 millennia.

Discussion

The resolution of the ITC model facilitates several provisional interpretations concerning hydrographic and climatic trends peculiar to the Harappan period. For purposes of discussion that period refers to the interval 3500-1500 BC. Initially, the hydrographic model (Figure 3) underscores the sustained stabilisation of Early Holocene drainage environments, subsequent to the disequilibrum of the terminal Pleistocene, where discharge rates fluctuated dramatically as fluvial systems approached a steady state. These observations are fully

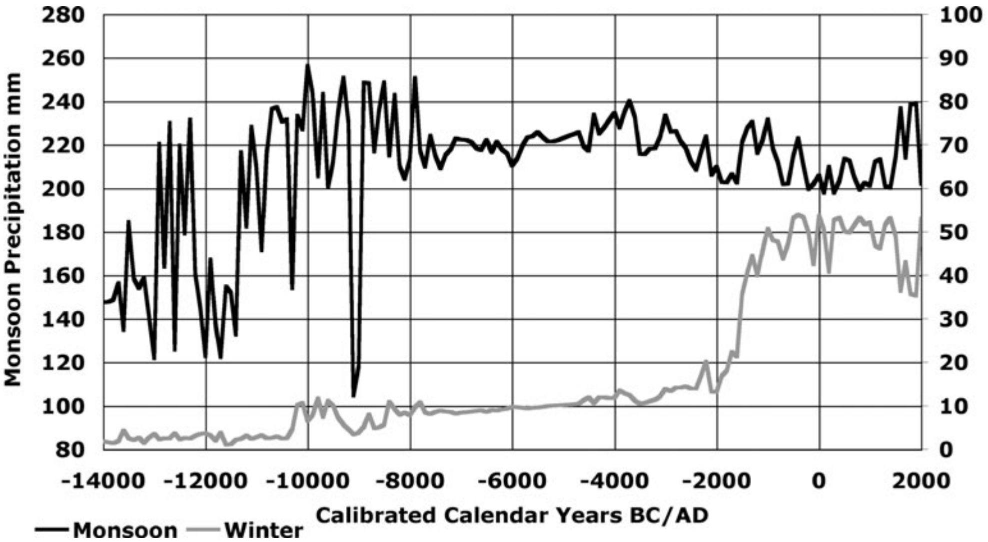

Figure 5. Modelled seasonal precipitation history at Sahiwal, Pakistan (near Harappa).

consistent with documentation of the Qadirabad soil that was dated to 10 000-7000 BP along the Beas (Schuldenrein *et al.* 2004: 795; Wright *et al.* 2005a) and argued for reduced net aggradation along the Beas for this time-frame. The discharge rates argue for a significant subsequent surge in flooding after 4000 BC (mean rates accelerate by >25 per cent; Figure 3) and a turn to more subdued accretion levels (550-575m^3/sec) for the duration of the Early and Mature/Urban Harappan before falling and restabilising towards the end of the Late Harappan phase. Regional interpretations have argued for channel avulsion and displacements of low lines at around that time in the Ghaggar Hakra (Courty 1995), perhaps in response to the destabilising event signalled by the low discharge trough around 2000 BC. It is noteworthy that post-Harappan discharge ranges are considerably narrowed (to a range of 530-470m^3/sec) and suggest that the steadier flow regimes analogous to those of the earlier Harappan period was probably the highest registered over the entire course of the Holocene in the Upper Indus area.

Next, the precipitation graphs inform both on the magnitude of the precipitation change and the temporal trend of such change in the immediate Beas and Harappa site regions (Figures 4 and 5). For the Early Holocene annual precipitation rates increase steadily but slowly, reinforcing both the discharge data (Figure 2) and the soil and sediment observations (Schuldenrein *et al.* 2004) for protracted environmental and landscape stability through 5000-4000 BC. After 3500 BC, however, net precipitation volumes fluctuate drastically for the 2000-year interval conforming to the duration of the Harappan occupation. Mean running rainfall totals range from a peak of 300mm (*c*. 3000 BC) to a minimum of 240mm (reduction of 20 per cent; *c*. 2000 BC). These dramatic transitions conform to the contemporaneous trough in discharge volume (see Figure 3) and would appear to confirm a sudden drying event that is again consistent with the channel displacements of the Ghaggar-Hakra and, perhaps, to low flow in the Beas at around the time of Mature/Urban Harappan. After that period there is another dramatic change in precipitation, as rainfall initially surges to the Holocene maximum around 1000 BC. The subsequent cycle is characterised by high amplitude periodicity and an irregularity that may be linked to the abandonment of existing agricultural landscapes.

Further refinement of the climatic regime is facilitated by an assessment of changes in moisture patterns. The variability is best gauged by the dynamic relationships between monsoon (summer) and winter rainfall totals (Figure 5). Here again, the Early Holocene is characterised by continuity, with monsoon rainfall totals averaging around 220mm and winter volumes at 100mm per annum. However, as shown in Figure 5, during the Mature/Urban Harappan period there is an inverse, co-varying trend in rainfall seasonality, as yearly monsoon precipitation diminishes while winter rainfall increases almost proportionately. A broad measure of such change is the monsoon to winter rainfall ratio. For the Early Holocene this ratio is almost unchanged over four millennia at 2.2. However, during the critical Mature/Urban Harappan, the index is 1.6 (a drop of nearly 28 per cent). The post-Harappan index is further reduced to 1.2.

The significance of this changing ratio in seasonal precipitation is that it is a measure of rainfall distribution. The lower the ratio, the more even the annual rainfall. In sorting out the pre-occupation (Early Holocene) and post-occupation (roughly Late Holocene) rainfall patterns, it becomes clear that during the Middle Holocene—or Mature/Urban Harappan—there was a transition from strong seasonal rainfall to a more uniform moisture distribution. As noted above, if this is the case, then it is arguable that the emergence and florescence of the agricultural system is partially attributable to a more uniform rainfall pattern which allowed for more stable landscapes and more effective management and farming of agricultural fields. The two-season (winter/summer) multi-cropping system noted above may have been a conscious strategy considering these fluctuations.

The sustained trend to more uniform rainfall during the Harappan may eventually have had a deleterious effect on agricultural productivity. Viewed quantitatively, the drop of the monsoon to winter rainfall index beneath 1.5 corresponds to the abandonment and dispersal of settlements and the decline of the culture generally. Whether or not this measure signals thresholds in precipitation balance or discharge regime (or both) is unclear, but the correspondence is unmistakable. Certainly the effects of changing hydro-climatic cycles warrant more pointed investigations into the human ecology of the Indus civilisation at the time of the Middle to Late Holocene.

Conclusions

The hydrographic and climatic models presented here suggest that at around the time of the Harappan emergence, stream activity and precipitation patterns underwent dramatic transitions following over 4000 years of Holocene stability. Geomorphological and pedological evidence points to realignments of channels in the immediate vicinity of the Harappa site (Amundson & Pendall 1991; Pendall & Amundson 1990a; 1990b), as the Ravi River migrated north during the Late-Harappan period (*c.* 2000 BC) and soils formed on relatively stable alluvial surfaces along the Beas, as we have discussed elsewhere for Lahoma Lal Tibba and Chak Purbane Syal (Wright *et al.* 2005a).

The combined climatic modelling, geomorphic data, settlement onset and eventual abandonment on the Beas, and multi-cropping patterns known from Harappa provide reinforcing lines of evidence for new and testable hypotheses concerning the complexities of human ecology during this critical period in the history of one of the world's ancient civilisations. This is facilitated by the use of the robust integrative hypotheses provided by the type of climate model applied in this paper.

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