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Endogenous change: on cooperation and water in ancient history

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Abstract

We propose and test the theory of endogenous change based on historical reconstructions of two ancient civilizations, Indus and Hohokam, in two water scarce basins, the Indus basin in the Indian subcontinent and the Lower Colorado basin in Southwestern United States. The endogenous institutional change sees changes in institutions as a sequence of equilibria brought about by changes in "quasi-parameters" such as rainfall, population density, soil and land use induced water resource availability. In the historical reconstructions of ancient civilizations, institutions are proximated by the scale of cooperation be it in the form of the extent of trade, sophisticated irrigation network, a centrally planned state or a loosely held state with a common cultural identity. The "quasi-parameters" either change naturally or are changed by humans and the changes affect the stability of cooperative structures over time. However, human influenced changes in the quasi-parameters itself are conditioned on the scale of existing cooperative structures. We thus provide insights into the quantitative dimensions of water access by ancient populations and its co-evolution with the socioeconomic and sociopolitical organization of the human past. We however do not suggest that water manipulation was the single most significant factor in stimulating social development and complexity – clearly this has been shown as highly reductionist, even misleading. The paper cautiously contributes to proximate prediction of hydrological change by attempting to understand the complexity of coupled human-hydrological systems.

1 Introduction

The number of studies concerning how we best incorporate our planet's limited and now diminished resource base and provide insights into how best to sustain them is growing (Costanza et al., 2011; Fisher, 2009; Janssen and Anderies, 2007; Lansing, 2003; Mithen, 2012). In this paper we provide insights into the quantitative dimensions of water access by ancient populations as it informs important aspects of the kind

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and degree of socioeconomic and sociopolitical organization influencing the human past. This is not to say that water manipulation was the single most significant factor in stimulating social development and complexity – clearly this has been shown as highly reductionist, even misleading. Nevertheless, water remains the most primary of resources on our planet and the most precious all resources that humans can control – more so than even food. It requires major energy outlays to command and significant infrastructural advances to accommodate population densities and growth of scale.

Once we can articulate how past water systems were – implicitly or explicitly – organized and used, we are in a position to evaluate aspects of their societal institutions. "[. . .] the systems with the best chance for uninterrupted longevity have slowly evolved on the highly variable landscapes from which people make a living. Even under appreciable stress, water management systems tend to persevere because of their adaptability. This aspect of water management receives less attention because it is less spectacular than the origin or collapse of a system. Nevertheless, societal maintenance and sustainability deserve greater scrutiny in our rapidly changing world." (Scarborough, 2003; p. 3–4). Archaeological case studies provide the longue durée necessary to properly assess system robustness. Learning how resilient these environmental investments may or may not have been and establishing parameters of societal success – the latter something that the archaeological record already provides – becomes a principal means of identifying a comprehensive notion of "sustainability".

In this paper, we build upon the theory of endogenous institutional change proposed by Greif and Laitin (2004) for water scarce regions. The current emphasis on environmental change, and hydrological change in the context of institutions in dry lands, largely ignores the adaption of human societies to change. Human actions and institutions have mostly been considered as mere fixed boundary conditions for hydrological processes or as parameters describing the dynamics of hydrological change but not considered as conduits of feedbacks themselves. Nonetheless, the dynamical representation of hydrological change with feedbacks between various components of a system is key.

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Such a feedback approach is reminiscent of processual ecological anthropology (Orlove, 1980), and provides a framework to incorporate human decision making and corresponding feedbacks in the broader dynamics of hydrological change. We selected two dry land areas of the world – the Indus basin in the Indian subcontinent and the Sonoran desert in modern USA – for which we conceptualized proxies of water relevant socio-economic organisation(s), specifically focusing on spatial-institutional scales of upstream-downstream cooperation synthesized over time, in order to propose a comparative assessment methodology to test regularities predicted by an extension of river game theory (Ambec and Sprumont, 2008) to endogenous institutional change. Figure 1 illustrates the proposed idea.

We start with a description of the theory of endogenous change, after which we discuss how two ancient civilizations – the Indus and Hohokam civilizations – can be understood from such perspective. We end with a discussion on these civilizations and the implications of our findings for further work along the lines we developed.

2 Theory of endogenous change

A basin is conceptualized as a collection of interconnected sub-basins where each sub-basin represents an agent who engages in water intensive production activities (Pande et al., 2011; Fig. 2). Connectivity between any two sub-basins is either due to the flows between them (hydrological) or due to trade or other forms of interaction (economic). For this paper, the possibility of satiated agents is ignored since it is less vital as we focus on water stressed dryland areas. The presence or absence of cooperation at any spatial scale is the proxy for "organization" of individuals, while the choices that agents make regarding land use and water extractions are conditioned (act as "rules") by the nature of coalitions formed. The nature (and as such the scale) of cooperation is an organization of individuals with rules that condition their choices of resource use. It can be in the form of upstream-downstream trade, sophisticated irrigation network,

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a centrally planned state or a loosely held state with a common cultural identity and serves as a proxy for institutions.

Institutions are defined as systems of organization, and rules that influence individuals decisions of resource use (Greif and Laitin, 2004). The organization of agents at basin scale is an appropriate unit of analysis in context of hydrologic change due to hydrological and hydraulic connectivity between agents that is internalized at that scale (Pande et al., 2011). Such connectivities are affected by present day actions that are partially the result of institutional rules and which constrain future actions of the agents. Such feedbacks also influence future change in the hydrological state of the basin. Studying change in context of evolution of rules requires the understanding of processes that generate such rules, and that select and/or retain rules based on certain criteria such as resource use efficiency (Ostrom and Basurto, 2011). Historical institutionalism (Thelen, 1999) focusing on the process or the dynamics of change allows understanding and conceptualizing many such processes, including Darwinian notion of evolution (Steinmo, 2008) and efficient capture or dissipation of energy (Vadya and McCay, 1975).

However, such processes of change have often been criticised; it has been argued that the applicability of efficient energy capture and dissipation is not applicable for system evolution in energy limited environments. Further, the unit of analysis in such processes of change are often ambiguous. The dynamics driven by optimality principles such as the survival of the fittest or maximizing energetic efficiency or productivity may be applicable to individuals but perhaps not to the system as a whole (Vayda and McCay, 1975). This notion underlines the need to develop theories that can describe system properties, group formation or dissolution and corresponding processes of decision making in terms of the attributes of their component individuals (Boissevain, 1968; Hall, 2010). This corresponds closely to Dopfer et al.'s (2004) micro-meso-macro architecture to understand the nature of existence of and change in evolution. Here the micro-domain refers to the individuals that execute the rules while meso is the scale at which process of rule change occurs. The macro component refers to the population of

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systems under change and plays a critical role in comparative analysis to understand the nature of change.

A rationalist model of institutional change, for example based on microeconomic decision-making of individuals and game-theoretic group formation, offers a credible process of rule change that can describe system properties, group formation and processes of rule change in terms of constituting individual attributes (Hall, 2010). Its friction with historical institutionalism that it is a study of stable equilibria can be eased based on the dynamics of historical institutionalism itself (Greif and Laitin, 2004). We however recognize that the rationalist model can never fully accommodate the complexity of interrelationships between individuals and institutions (Greif and Laitin, 2004; Hall, 2010). For example, the role of social norms and the process of "reinterpretation" of meaning that agents associate with institutions and change (Thelen, 2004 in Hall, 2010), choice made between multiple equilibria, institutional persistence (the notion of punctuated equilibrium of Thelen and Steinmo, 1992) and the notion of "ideas" as a solution to collective problems that precipitates change (Steinmo, 2008) are effects difficult to quantify or rationalize. Institutional change resulting from hydrological change is equally complex since institutional change can usher in due to social, political or economic factors that are not linked to hydrological change (Geertz, 1972; Burns, 1993; Komakech et al., 2012).

Yet a rationalist or a game theoretic foundation provides a formal basis to understand and predict institutional change in a proximate manner. This is more so in water scarce areas where institutions and hydrological system often coevolve. River games offer such an opportunity (Ambec and Sprumont, 2002). Any proximate prediction of institutional change accompanies that of hydrological change due to the co-evolutionary nature of institutional and hydrological change. It thus underlines the need to carefully examine the limits of the rationalist model to prediction of institutional change in a comparative setting.

We perform a comparison at basin ("meso") scale across two basins in dryland areas and present a historical comparative assessment of endogenous change. The

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institutions used as proxies of the scale of upstream-downstream cooperation range between no-cooperation and cooperation between subbasins at the basin scale, such as irrigation systems (Komakech et al., 2012). The theory of cooperative cores (Shapley, 1967) is applied to the river basin games that determine the presence or absence of cooperation either at basin scale or at finer scales between certain subbasins. Here, the connection between hydro-climatological and demographic attributes of subbasins (such as rainfall, population density, land use etc.) and institutions is characterised by the core stability conditions. These conditions depend on the attributes and determine the scale of cooperation.

Recently Pande (2013) demonstrated that heterogeneity in the autarkic valuation of agents (or subbasins), which depends only on an agent's local rainfall, population, soil, land cover and choice of production activities, are important determinants of the scale of cooperation at basin scale. The autarkic valuation of agents is a measure of local scarcity. The effects of such heterogeneities on cooperative water allocation have also been found at field scale (see e.g. Komakech et al., 2012). In particular, the spatial distribution of autarkic valuations is an important determinant of the stability of coalitions in a basin.

In the case of water stressed regions, the river network topology strongly determines the interaction between subbasins and institutional development. Then an ordering of autarkic valuations from the most upstream agents to the most downstream agent is sufficient for a basin scale cooperative structure to emerge (Pande, 2013). The determinants of autarkic valuation of an agent such as population, landcover and production activities are the "quasi-parameters" that the agents then alter, altering local scarcity conditions relative to others and thus stability conditions in the future.

We propose to extend and apply this theory to dynamical setting by recognizing that agents adjust "quasi-parameters" over time conditioned upon the current nature of cooperation (proxy for institutions), and determine the co-evolution path of water use and institutions by determining the stability conditions for the future (Fig. 3). Historical

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reconstructions of two basins (Indus and Lower Colorado) are utilized to test the regularities predicted by the theory, through a comparative assessment of the basins.

3 Indus valley civilization (Harappan civilization/tradition)

3.1 Chronology of the Indus valley civilization

Several civilizations flourished in the Indian subcontinent between 5000 BP (Before Present, present = 1950) and 2000 BP (Fig. 4). The Indus valley or the Harappan civilization (or tradition) flourished in the Indus valley between 3900 BP and 4500 BP. The Helmand tradition flourished around the same time as the Harappan civilization. Other civilizations in the area such as the Baluchistan tradition, Ganga-Vindhya tradition and the Deccan traditions appeared after the decline of the Harappan civilizations around 2500 BP. The transition between the decline of the Harappan and the emergence of these traditions was dominated by the Indo-Gangetic tradition that included settelements or even chiefdoms in eastern regions of the Indus valley, in Rajasthan and Gujarat and in the western to central parts of the Ganga-Yamuna doab (Kenoyer, 2006, 2011).

The early settlements in the Indus valley began to appear around 9700 BP in the western parts of the Indus valley such as in Mehrgarh, Gumia and Riwat (Kenoyer, 2011). This was the transition of human societies from foraging to early food production and domestication of animals by settling along the fertile banks of the Indus river and its tributaries. However during this early food producing era that continued uptill 7200 BP, the population engaged both in foraging and food production (Fig. 5a). The area witnessed population growth and rapid increase in the number of settlements (Fig. 9) till 5200 BP when the population centers started to interact (MacDonald, 2011; Madella and Fuller, 2006; Kenoyer, 2001). The interaction network spanned from Amu Darya in Central Asia to Dolavira in the present day Kutch, Gujarat (Fig. 5b). The interaction network evolved over time possibly as a result of increasing specialization due to spatial

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heterogeneity in resource availability and population pressure. It marked the beginning of the early Harappan phase that from 5200–4500 BP was regionalizing the identity of Harappan civilization to a loosely held state (Fig. 5c). The city of Harappa served as major hub linking settlements in the north and the northwest of the Indus basin to the south. Between 4500 and 3900 BP, settlements in Harappa in the north, Mohanjodaro and Dholavira in the south emerged as major urban centers. Several population centers also emerged along the Saraswati and Ghaggar-Hakra river (the Cholistan). This period marked the peak of the Harappan civilization with a strong trade network. Even though the Indus civilization never realized itself as a centrally planned state and the major urban centers had its own clans competing for power, the interdependencies between the urban centers and other centers was sufficiently strong to render Harappan civilization a quasi-statehood (Kenoyer, 1994, 2006). The area settled was at its maximum in the history of the civilization, reflecting the growth in population and opulence resulting from gains in efficiency through specialization and trade (Vahia and Yadav, 2011; Madella and Fuller, 2006).

The period between 3200–3900 BP witnessed the decline of the civilization (Fig. 5d) with a movement of population to the east upto the Ganga-Yamuna doab. The span of influence, through trade and other interactions network, that rendered Harappa its identity as a state, collapsed back into settlement areas to the west, south and east with little or no interaction between them (Madella and Fuller, 2006; Kenoyer, 2011). Several theories have been proposed for the demise, including violent invasion from the northwest and abrupt climate change that lead to severe water scarcity conditions across the basin (Kenoyer, 2006; Staubwasser et al., 2003). The Saraswati and the Ghaggar-Hakra river had dried by this time, possibly due to tectonic activity that diverted its headwater to the Yamuna river basin (Madella and Fuller, 2006).

3.2 The debate

While many agree that climate change may have contributed to the demise of the civilization, strong disagreements between paleo-climatologist, cultural anthrolopologists

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and archeologists remain on the process of the demise. The uncertainty in the radiocarbon dating of archeological evidence is one cause of disagreement (MacDonald, 2011). The transition for the Harappan civilization from its mature urbanized era to its late era of population dispersal was around a major climatic event. The paleodischarge record based on the core data from the Arabian peninsula off the coast of Gujarat indicates that the Indus discharge into the Indian ocean significantly dropped around 4200 BP (Fig. 6). This event has been recorded in several other paleo records and has been blamed for the collapse of other civilizations such as the Mesopotamian (Staubwasser and Weiss, 2006; Bar-Matthews et al., 2003). However, it has also been argued that Harappan civilization matured from a collection of towns or settlements to a quasi-state with several urban centers in the face of increasing water stress, to the extent that it was flourishing even after the 4200 BP event (MacDonald, 2011; Madella and Fuller, 2006). The 4200 BP at best triggered a change in the organization of human societies that took time to take effect.

3.3 Spatial distribution of scarcity conditions matters

The theory of endogenous change supports the latter argument. As many others have argued, the demise of the Indus civilization was probably more complex than as a result of an abrupt change in climate. Other variables such as resilience of human societies, prevalent institutions (that are proxies of cooperative structures) and technology matter as well (Vahia and Yadav, 2011). Further, it is possible that the effect of climate change was not sudden and uniform throughout the basin. Since the spatial distribution of scarcity conditions engender cooperative structures, a cooperative state such as the Harappan civilization could have survived extreme scarcity conditions if the distribution was favorable.

Different water resource scarcity conditions at different locations facilitate specialization in the production of food and other commodities. This ensures that the scarce resource is used efficiently. Trade and interaction between different areas enables a distribution of products from such specialization based on local valuation of these products.

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In the Indus basin, transition between early and mature Harappan era witnessed winter as well as summer crop production throughout the basin. As the mature Harappan era progressed, winter crops were grown more in the north and north west regions while the south and south eastern parts specialized more in summer crops (Madella and Fuller, 2006). Strong trade network and local scarcity conditions enabled the distribution of food throughout the year with sufficient surplus to support the roles of the administrates and the clergy. It resulted in the functioning of a quasi-state with institutions that reflected a cooperative structure at the basin scale. The scale of cooperation also facilitated technological innovation in water management and infrastructure, which ensured even more efficient use of water resources (Vahia and Yadav, 2011).

However, as the theory of endogenous change suggests, the appearance of a cooperative structure due to trade or interaction depended on local valuations. Local specialization in producing winter or summer crops without any interaction between the population centers was a non-cooperative structure. Each region then had to support its population based on its own production. The cooperation between the regions appeared when the regions found it mutually beneficial to trade the products they specialized in. Any change that affected the nature of mutual benefits between regions affects the nature of cooperation.

We attempt to explain the rise and the demise of the Harrapan civilization in this context. Our qualitative analysis suggests that it was the interplay between the strengths of winter monsoon and the summer monsoon that led to the Harappan rise and fall.

3.4 Paleoclimatic evidence

The winter monsoon in the Indian subcontinent originate near the eastern Mediterranean (Staubwasser et al., 2003; Staubwasser and Weiss, 2006). The paleorainfall record from Soreq Cave in Isreal (Bar-Matthews et al., 2003) suggests that the strength of winter monsoon in the Indian subcontinent weakened over the Holocene. Meanwhile the paleo SST (sea surface temperature) record of the western tropical pacific (Stott, 2008) suggests first an increasing trend, followed by a decreasing trend around the

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beginning of early Harappan phase (Fig. 6). Both the paleo records, given their correlation with the winter and summer monsoons (McDonald, 2011), suggest that the monsoons stabilized to the current climatic condition in the late Holocene period around the collapse of the Harappan civilization.

The early Harappan phase witnessed an increase in the winter monsoon strength (Fig. 7). It peaked and started to decline around the period when the Harappan civilization entered its mature phase. Meanwhile the summer monsoon strength was declining throughout early to the late Harappan phase. Thus the Harappan civilization urbanized in the face of declining summer and winter monsoon strengths. This was also recorded by the Indus paleo-discharge data (Figs. 6 and 7). However the detail of the mechanism of institutional change from urbanization to decline is not so evident in the paleo-discharge. It is instead in the changing strengths of the monsoons and hence the spatial distribution of water scarcity conditions. Note that during the transition between early to mature Harappan phase, the Indus valley also witnessed increasing population pressure that added the social dimension of scarcity.

3.5 The rise and the dispersal of the Harappan civilization: role of the monsoons and the spatial distribution of scarcity conditions

The winter season crop production in the Harappan civilization coincided with the increasing strength of the winter monsoon towards the end of early Harappan civilization (Fig. 7). The population in terms of the number and area of settlements also grew that was sustained by the relative abundance of water and fertile land (Fig. 9). This implied local abundance of food, which ensured a carrying capacity that was sufficient to meet local demands. Given the relative abundance of rain and low population density (Fig. 9), the need to trade for subsistance was low although various population centers were interacting (Kenoyer, 2001).

The weakening of winter monsoon during the mature phase and ever decreasing strength of the summer monsoon created the avenue for cooperation (Fig. 7). Weakening winter monsoon meant that the monsoon penetrated the Indus valley to a lesser

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extent. The eastern parts of the Indus civilization shifted to summer crops meanwhile the north and the northeastern parts retained their specialization in winter crops (Madella and Fuller, 2006). Weakening summer and winter monsoon for the eastern and southern parts meant scarcer water conditions relative to the north and northwestern parts that still received water from the Indus river and its tributaries in relative abundance. This gradient of increasing water scarcity conditions in the downstream direction under overall increasing scarcity condition favored upstream-downstream cooperative structure at the basin scale.

Thus strong trade links throughout the basin and cultural uniformity, even though there was never a centrally planned Harappan civilization, prevailed during the mature era of Harappan civilization (Kenoyer, 2006). The non-zero sum nature of cooperation implied that both the upstream and downstream areas of the basin gained from the cooperative structure. This meant that there was surplus enough that elite classes emerged and overall population blossomed (Fig. 9). The major urban centers such as Harappa and Mohanjodaro saw powerful families competing to rule (Kenoyer, 2011). The society was more stratified.

However, the gains from mutual cooperation and trade soon thinned out due to further weakening of the summer and the winter monsoon (Figs. 7, 8). While the civilization efficiently used water resources through innovative irrigation and other water resources management technologies, it needed newer technological innovation to cope with ever increasing water stress (Vahia and Yadav, 2011). The sudden population growth throughout the mature phase meant increased stress on the food production system (Madella and Fuller, 2006) and required improved food production technologies such as in the farming system. Several such much needed technologies such as the use of horses appeared late (Vahia and Yadav, 2011). Around the transition from mature to late Harappan era, the Ghaggar-Hakra and Saraswati rivers had dried out possibly due to non-climatic causes. This meant further population stress on other settlements on the Indus river and other perennial rivers. The weakened winter monsoon further resulted in reduced seasonal snow in the headwaters of the Indus river system, which strained the water supply of an already stressed system (Staubwasser et al., 2003).

In the light of the theory of endogenous change, changing monsoon strengths and increasing population pressure could have resulted in an unfavorable spatial distribution of water stress conditions that led to the collapse of the cooperative structure at the basin scale. This demise is the late Harappan era, when the scale of the cooperative structure collapsed from the basin scale to smaller autarkic units or isolated settlement areas (Figs. 8, 9). The weak or absent trade links between the late Harappan settlements indicate that it was no longer beneficial to cooperate and that those societies were better off locally by sustaining their population through local production (Madella and Fuller, 2006). Locally high stress conditions also implied that population outmigrated from the basin to less stressed areas of the Indo-Gangetic plains (Fig. 8). Thus the decline of the Indus civilization coincided with the emergence of other civilizations in the subcontinent such as the Ganga-Vindhya traditions and the Deccan tradition (Kenoyer, 2006).

4 Hohokam civilization

The Hohokam is an archaeological culture found along the middle Gila and lower Salt Rivers in the Phoenix basin in the Sonoran desert. The Hohokam occupied that area roughly between 0 AD and the middle of the 15th century AD. The Hohokam culture may be re-known for two things: their extensive irrigation canals, which were found by European settlers and their apparent disappearance after roughly 1450. As such, the Hohokam is a popular symbol for the risks societies run when relying on a single source of food production and when they overstress that system. Obviously, the real story is more complex.

It is true that irrigated agriculture was important for the Hohokam, but they also relied rather heavily on harvesting wild plants, and they hunted animals as well. The principal field crops were maize, beans, cucurbits, and cotton. Agave was an important wild

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plant, used for both fiber and food, but it seems to have been grown within irrigated systems along canal banks. Mesquite was a very important wild plant, both for food and wood (Gasser and Kwiatkowski, 1991; Hodgson, 2001; Rea, 1997). Wild mammals being hunted and/or used include rabbits and hares, small rodents, white tail and mule deer, pronghorn antelope and mountain sheep, as well as birds and fish (Fontana, 1983; Rea, 1997).

The Hohokam period is generally divided into four periods: the Pioneer (AD 450–750), Colonial (AD 750–950), Sedentary (AD 950–1150) and Classic (AD 1150–1450) period (Woodson, 2010). Abbott et al. (2003) define the Classic period between AD 1100 and 1375, after which the so-called Polvoron Phase (AD 1375–1450) is found. During the Pioneer to Sedentary period the Hohokam culture was spatially at most extended of all phases, with ball courts spread widely over huge areas. In the Classic period major changes occurred.

"In contrast to the clustered and patchy spacing of platform mounds, the ball courts [of the Sedentary period] had a continuous distribution, expressing uninterrupted connections among communities across a vast region. The reorganized settlement pattern of the Classic period into discrete clusters, therefore, exemplified a retreat from interstitial areas and possibly a new and divided social order" (Abbott et al., 2003, p. 5).

It is this change in the Classic period that is of clear interest to a study of the relations between human civilization and natural environment.

In the Classic period, the Hohokam settlements in the Sonoran Desert are found in six clusters: the lower Salt and middle Gila River valleys of the Phoenix basin, the Tonto basin, the lower San Pedro River valley, the Tucson basin, and the eastern Papaguería (Abbott et al., 2003, p. 5; see Fig. 10). Of these six areas, the Lower Salt and Middle Gila areas were by far the largest in terms of population, dominating the overall population figures over time. Figure 11 shows these figures. It is clear that the total population grew until the start of the Classic period, but started to decline in the second half of the Classic period. At the end of the Classic period, population estimates go down.

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Originally, as the name suggests, the Classic period was seen as the core period of a flourishing Hohokam civilization. However, this may not have been the case, as a study on Pueblo Grande, one of the larger settlements in the Salt basin shows.

"Despite the society's achievements – represented by its monumental architecture and extensive hydraulic infrastructure – life was harsh along the Salt River. Overpopulation, environmental degradation, resource shortages, poor health, social fragmentation, diffuse and ineffective leadership, and a struggle to cope are the characteristics that we use to describe the turmoil of the Classic period in the Phoenix basin. We view it as a time of widespread decline, not prosperity, and a precipitous slide toward the eventual abandonment of a homeland that had been occupied for approximately fifteen hundred years." (Abbott et al., 2003, p. 4–5).

In short, in the Hohokam we find a civilization that has experienced profound changes in its history, changes which are closely linked to their exploitation of their environment and the changes in that same environment. A main element of the environment was water availability, and as will be discussed below, in Pueblo Grande and the irrigated system from the Salt River, there is evidence suggesting changes in management of the vital irrigation systems. The story of the Hohokam is complex, however, as the different core areas may have witnessed different conditions.

Changes and water in the Hohokam areas

The reconstructed data series on precipitation in the Phoenix area are available from from the "Tree-ring Reconstructions of Past Climate in the Southwest" project (http://www.climas.arizona.edu/projects/tree-ring-reconstructions-past-climate-southwest; accessed at 21 March 2013). The data is available from 1000 AD which covers our time period of interest and provides us with the cool season (November–April) precipitation reconstruction. The reconstruction shows that only a few years in the past thousand years were drier than for example 2002. On average, the winter precipitation did not change significantly in the last 1000 yr. However, several extended dry periods can be found, and particularly for our time period in the late 1000s-early 1100s, and the

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late 1200s-early 1300s. "The impact of the extreme periods on the environment may be stronger during sudden reversals from dry to wet, which were not uncommon throughout the millennium [...]" (Ni et al., 2002). Re-drafted graphs from this dataset are provided in Figs. 12 and 13.

These two drought periods are of interest to our analysis. The first one, coincides with a shift from the Sedentary to Early Classic period (Fig. 13). In this shift, "[...] abandonment of large tracts outside the major river valleys and a concentration of settlement mostly in or close to the riverine habitats" occurred. "Most analysts recognize this widespread demographic shift, and many theorists interpret it as a reduction in regional integration and a critical factor in the processes of cultural change [...]". What exactly caused this shift in settlement is still heavily debated in Hohokam expert circles, but it is clear that "[...] environmental instability, including changes from winter-to summer-dominant rainfall patterns [...] or a decrease in effective moisture [...], which would have made marginal agricultural land unproductive and reduced the number of suitable niches for irrigation" is one of the major candidates (quotes from Abbott et al., 2003, p. 10). Warfare is also a candidate, but obviously cause and effect are unclear, as increased environmental stress could lead to warfare and as such population concentration for protection, whereas warfare in itself could also cause concentration of people in more secure settlements.

Whatever the direct cause, it is clear that for the Pueblo Grande area the environment offered less possibilities in terms of plant and animal availability, and as a result human health deteriorated (Kwiatkowski, 2003; James, 2003; Sheridan, 2003). In an overall concluding analysis, Abbott described Pueblo Grande in the Classic period as a human population "struggling to survive tumultuous change" (Abbott, 2003; p. 201). For him, the Sedentary period, with its extensive spread of people over the area and dense evenly spread network of ball courts, was the major period of Hohokam civilization. A clear hierarchy on terms of settlements or elites controlling resource allocation and exchange is not found in this period.

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As a response to changes at the end of the period, the Hohokam seem to have reorganized themselves in sub-regional areas based on their irrigated areas. New social relations emerged between these areas, as the areas became more closed entities within the larger region. The late Classic period saw developments suggesting that those closed communities did relate to other groups; Abbott suggests that communities in so-called Canal System 2 – the core area of Pueblo Grande – built relations with communities in Canal Area 1 – upstream of Pueblo Grande. Apparently, when these ties were built, the eastern part of the valley (upstream) became less populated and more isolated. All these developments together may show a tendency towards a "multicommunity, centrally controlled, hydraulic network. Such complexities are usually associated with politically advanced, state-level societies [...]" (Abbott, 2003; p. 225).

Despite this development towards unity, at the end of the Classic period, a new period of drought and floods caused too much stress for the communities along the Salt River to sustain their communities (Fig. 14). The period between AD 1275 and 1349 had both the highest incidence of droughts and floods, compared to the period AD 1000 and 1275 (Kwiatkowski, 2003). For the settlement of Grewe in the Gila region, Ingram and Craig (2010) found that population figures decreased in above average wet conditions, which confirms that a period of floods would put high stress levels on Hohokam society. Especially a community dependent on irrigation would need to repair the heads of the canal systems after each flood event, which might have demanded more labour than available or willing. For dry periods, Ingram and Craig did not find negative influence on population growth, which may relate to the (upstream) position of Grewe or the period of analysis (relatively early). They did find negative effects of combined wet and dry years though.

Despite the clear signs of environmental change related to water and associated changes in Pueblo Grande, one needs to be careful in generalizing these findings for the entire Hohokam area.

When discussing irrigation management in the Gila and the possible changes over time, Woodson (2010) did not find big changes between Sedentary and Classic period

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in terms of irrigation organization. The Classic period did show lower population figures in the Middle Gila River as well as a different allocation of the population within the area. Larger settlements were partly abandoned and smaller settlements were formed. Woodson did find changes in the irrigation systems along the Gila River that may be related to changing environmental conditions and/or stress on the resources. During the Sedentary period, two irrigation systems – the Gila Butte Canal and the Snaketown Canal – were connected, perhaps to convey excess water from Gila Butte into Snaketown Canal. The Classic period shows another connection between the two canals, which may have been built to ensure that the now prevailing lower flows in the Gila River could still be brought to the downstream end of the system. However, irrigation management did not seem to have changed.

"Single-village systems generally were managed as a municipality, in which the authority for the political institution and the irrigation organization is the same. All four systems began in this form. Multi-village systems were managed by an irrigation community, in which the authorities for the irrigation organization and political institution are separate. Three and possibly all systems were managed by irrigation communities in the Sedentary period." (Woodson, 2010, p. iii).

5 Synthesis: a comparative assessment

The time scales at which the two civilizations evolved are different. The Indus civilization evolved over a period of 3 millennia while the Hohokam civilization evolved over 5 centuries. One may argue that such diverse scales may in part be due to the stochasticity in water resource availability. The Indus civilization witnessed a gradual decline in water resource availability (over 500 yr) in comparison to the Hohokam civilization, even though it is abrupt on archeological scale. As the Fig. 13 demonstrates, Hohokam society faced immense fluctuations in annual water resource availability. The runoff proxy suggests that it fluctuated between +2 standard deviations (wet to dry) and −1.5 standard deviations (extremely dry) about the mean over 500 yr. Such short time

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scale fluctuations must have interrupted the progress of institutions to maturity. This degree of stochasticity in annual water resource availability represents uncertainty that adds to the cost of building a coalition under water scarce conditions.

The Hohokam society faced dry condition on average (122 mm of rainfall over a 6 month wet season), wet to dry conditions on one extreme (with positive standard deviations) and extremely dry conditions on the other extreme. Water resource availability as well as its variability were both challenging the society. Meanwhile the water resource availability of the Indus civilization was driven by winter and summer monsoons that gradually declined in strength. Even though the two civilizations differed in scales of size and evolution, both the civilizations reached its peak under increasing scarcity condition and declined under extreme scarcity.

The Indus valley civilization urbanized and integrated it various settlements spanning the western part of the Indian subcontinent under increased scarcity condition (Figs. 5 and 7). This beginning of the decline in water resource availability was possibly due to the beginning of weakening winter monsoon. The summer monsoon had already been weakening for the past 1 millennium. It began its decline after the local minima of winter and summer monsoon coincided. The rise of the Hohokam civilization to maturity (from Sedentary to Classic era) also occurred during the period of extremely low annual precipitation around 1150 AD (Figs. 12 and 13). The available water was relatively low but not extreme (Fig. 14). It started to disperse around 1375 AD, under extremely low runoff conditions even though annual precipitation had not been extremely low.

While the spatial distribution of scarcity is evident in the case of Indus civilization, it is not so clear for the Hohokam civilization. However, it witnessed the condition of increasing scarcity that is necessary (if not sufficient) for the emergence of basin scale cooperation. The emergences of basin scale institutions led to efficient consumption of resources. It brought prosperity and consequently population growth with it. The quasi-parameters, population and water resources availability, (through land use) thus evolved, leading to increasing stress on the available resources up to the extent that its

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destabilized the cooperative structure in both the civilizations. That led to its decline, precipitated after extremely dry water resource availability.

It can be argued that both the civilizations declined due to the efficiency in consumption of resources brought about by basin scale cooperation. Efficient consumption led to an explosion in local population densities. Under no or slow technological innovations, increasing population implied increasing demand for resources at a carrying capacity that did not increase over time. However, the stress conditions were further exacerbated when the carrying capacity of the system was unfavorably perturbed. That was the case in both the civilizations. However the mechanism through which it precipitated differed.

The Hohokam, unlike the Indus civilization, faced severe volatility in water resource availability as proximated by the runoff proxy (Fig. 14). This implied fluctuations in its carrying capacity and amounted to severe uncertainty about the availability of future water resources. Such uncertainty, once realized by the cooperating agents in the cooperative structure of the Hohokam (the Classic era), was a cost. Uncertainty in resource availability often distorts the solution of an allocation game (Pande and McKee, 2007). There is also evidence that population migrated out of the coalition structure during relatively wet periods only to come back later due to recurring dry conditions (Ingram and Craig, 2010). This added further strain on the personal relationships and exacted another cost of personal nature on the coalition structure, weakening it over time. The extremely low runoff period, around 1400 AD, was a threshold that led to the collapse of the Hohokam cooperative structure.

Meanwhile the Indus civilization faced a gradual decline in monsoon strengths. The carrying capacity of the basin gradually declined while it faced ever increasing demand due to increased population growth. The cooperative structure was first resilient to the deficit between population demand and the carrying capacity that probably appeared around 4200 BP but the resilience could not sustain basin scale cooperation for long. The scarcity condition became sufficiently severe for some agents who could no longer afford being in the basin scale cooperative structure.

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6 Conclusions

The rise of a civilization to maturity implies an emergence of a cooperative structure (be it in the form of trade, sophisticated irrigation network, a centrally planned state or a loosely held state with a common cultural identity) at its spatial scale. The onset of the cooperative structure at the basin scale under increasing scarcity condition, though not yet extreme, is a regularity predicted by the theory of endogenous change. This is not to mean that the theory predicts the emergence of basin scale cooperation under any scarcity condition. This paper discussed that a cooperative structure appears when the spatial distribution of scarcity condition is such that cooperation is beneficial for all the settlements involved. Cooperation may not be the best strategy for all either under a condition of abundant resources or of extreme scarcity. In the case of abundance there is sufficient local availability of resources that dilutes the need to cooperate while under extreme scarcity many may find cooperation unaffordable. Thus, scarcity condition, that is not yet extreme, is a necessary condition for a cooperative structure to emerge. The spatial distribution of scarcity condition matters since scarcity is a reflection of local valuation of resource. It is only under a diversity of local valuations that different agents would be willing to cooperate. In case of systems connected at least by hydrology (such as the basins considered in this paper), scarcity increasing in the downstream direction is a sufficient condition for the emergence of basin scale cooperation.

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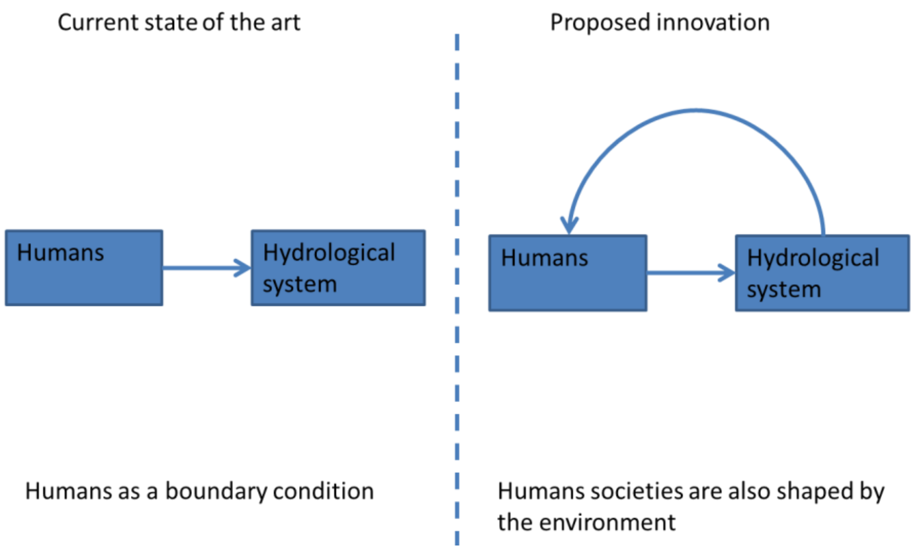

Fig. 1. An illustration of feedbacks between hydrological systems and human societies.

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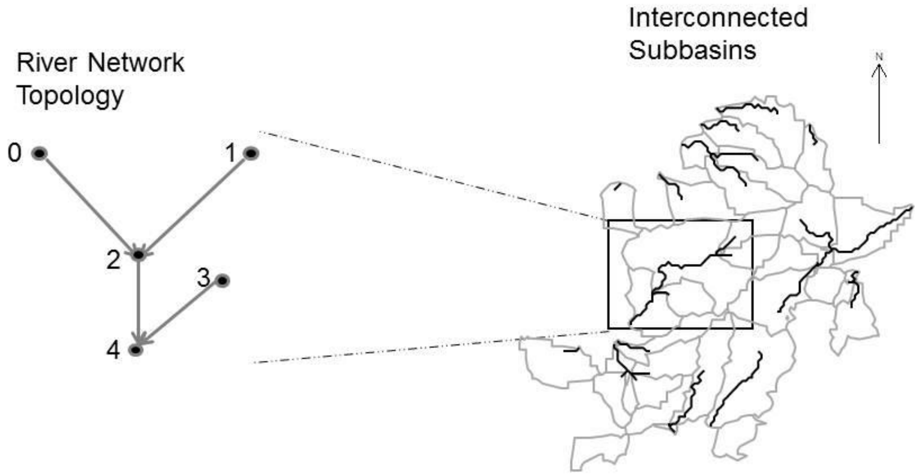

Fig. 2. Conceptualization of a river basin and a river network from Pande et al. (2011). Only hydrologic connectivity is conceptualized.

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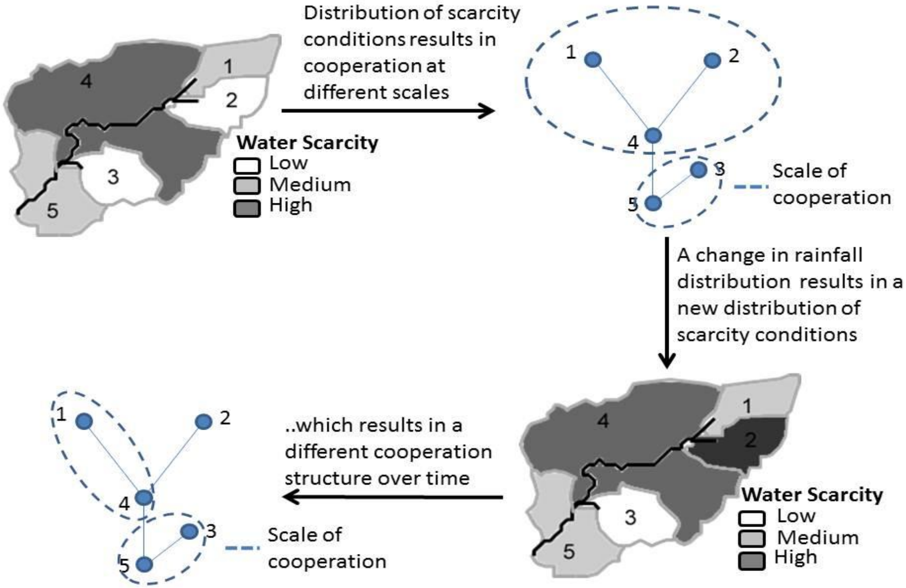

Fig. 3. An illustration of the theory of endogenous institutional change.

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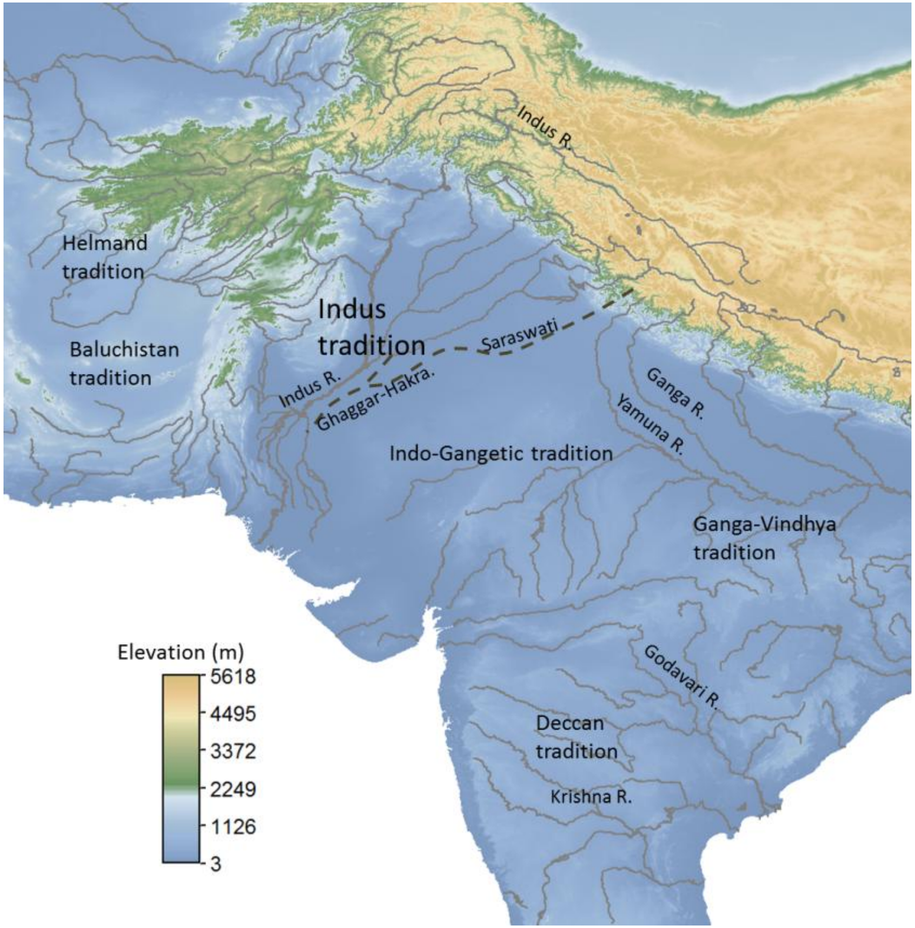

Fig. 4. The civilizations of the Indian subcontinent between 5000 and 2000 BP.

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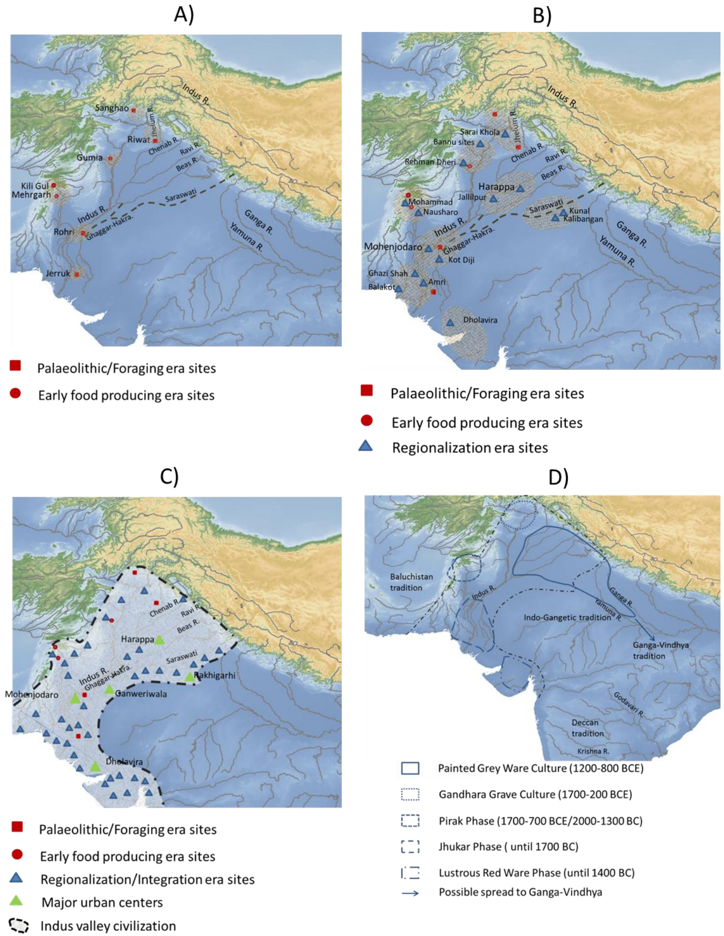

Fig. 5. The chronology of the Indus valley civilization. Compiled from MacDonald (2011); Kenoyer (2006, 2011) and Madella and Fuller (2006).

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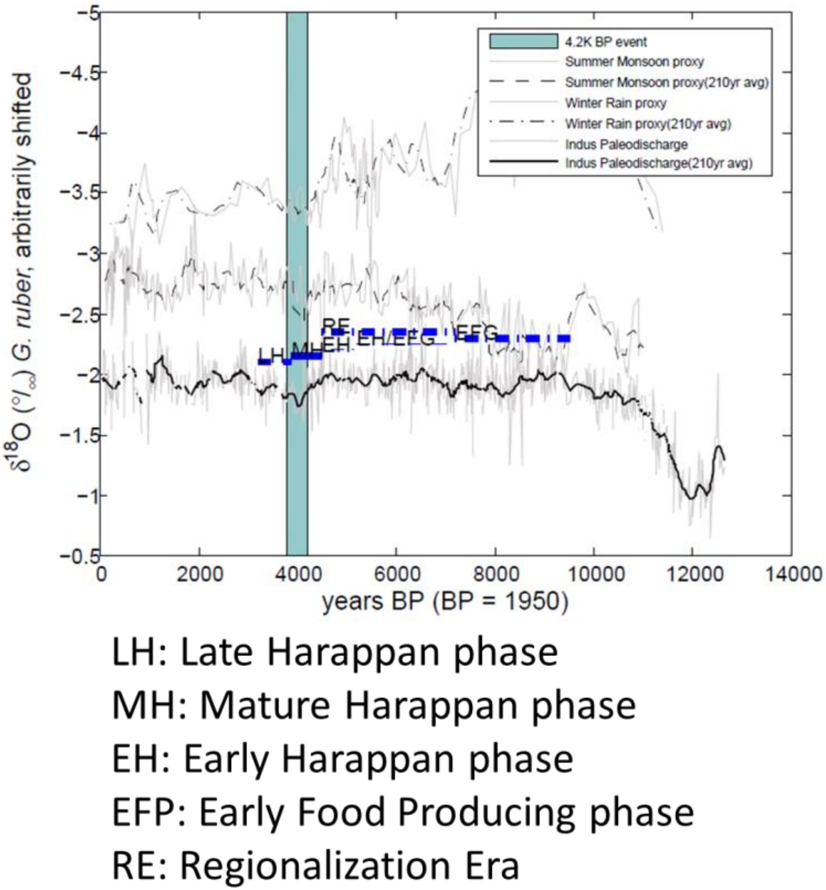
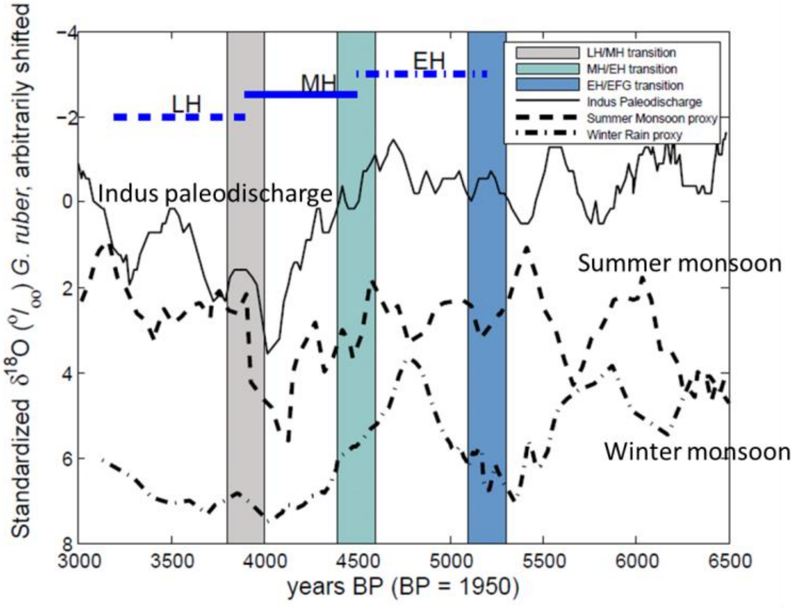


Fig. 6. The paleo-climatic proxies of the Indus river flow (Staubwasser et al., 2003), the summer monsoon (Stott, 2008) and the winter rain (Bar-Matthews et al., 2003) over the Holocene period. Lower negative value implies lower magnitude. Also indicated is the 4200 BP event.



LH: Late Harappan phase
MH: Mature Harappan phase
EH: Early Harappan phase

Fig. 7. The paleo discharge and monsoon record during the rise and the dispersal of the Indus civilization. The data is standardized by subtracting the mean and dividing by the standard deviation of the time series. Also shown are the transitions between EFG (early food producing) and EH; EH and MH and MH and LH. Compiled from Staubwasser et al. (2003); Stott (2008); Bar-Matthews et al. (2003) and Madella and Fuller (2006).

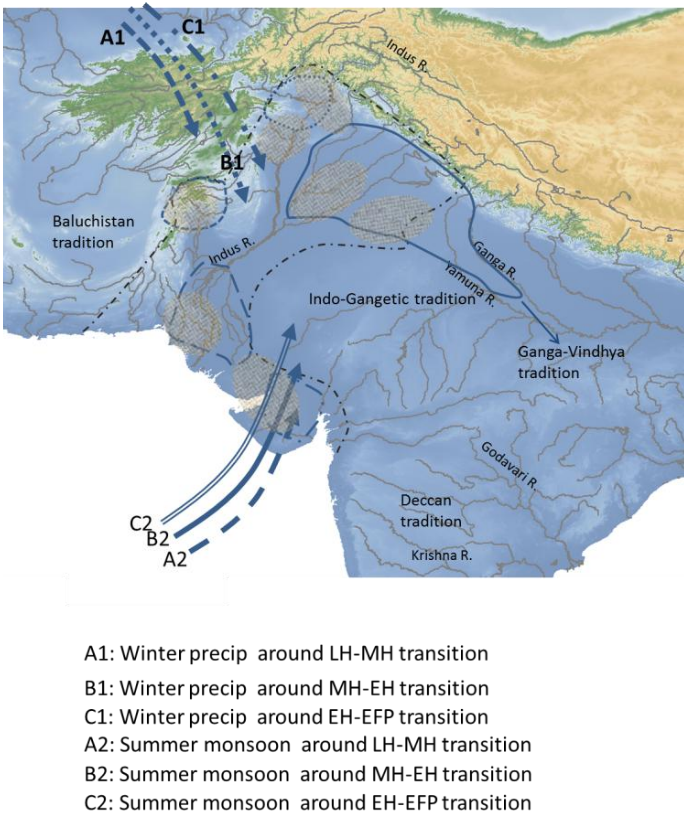


Fig. 8. The role of the strengths of the monsoons on the rise and the dispersal of the Indus civilization. The lengths of the arrows indicate the magnitude of the monsoons. The directions of the arrows coarsely describe the flow of monsoonal moisture. The hatched areas represent early Harappan settlements and the smaller enclosed shapes are the extents of late Harappan settlements. The extent of the mature Harappan era is represented by the dashed line.

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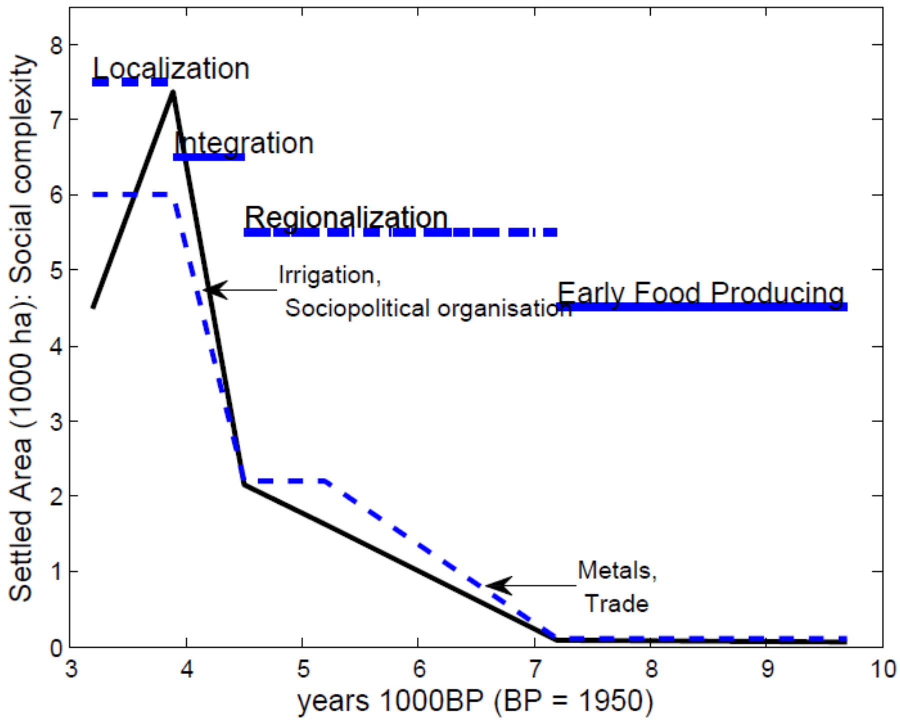

Fig. 9. The evolution of population density in terms of settlement area (after Madella and Fuller, 2006). Also shown are the various eras: Localization refers to late Harappan era, Integration refers to the mature Harappan, Regionalizaiton refers to the transition from the early food producing era to the early Harappan era. The dashed line represents the carrying capacity of the basin, adapted from Vahia and Yadav (2011), which shows that the transitions between the shown era was also complemented by technological innovations.

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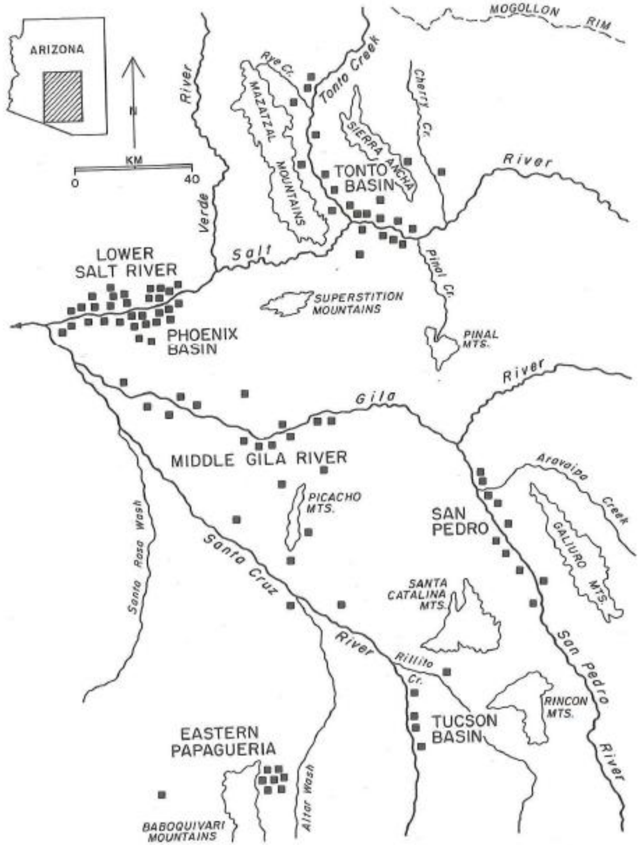

Figure 1.1
Distribution of Hohokam platform mounds
(after Doelle et al. 1995:fig. 13.1, p. 387).

Fig. 10. Main population centres of the Hohokam civilization (Abbott et al., 2003).

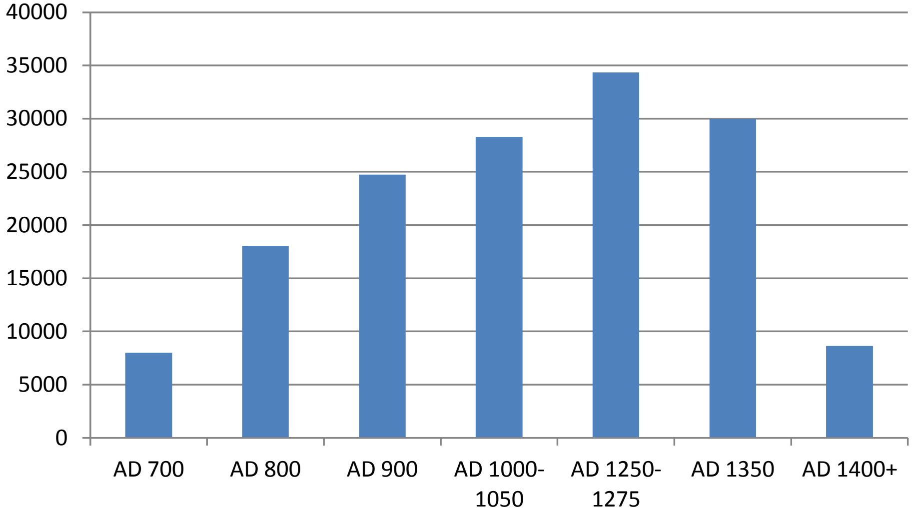

Fig. 11. Estimated total population for the Hohokam civilization, as reconstructed by the Long Term Vulnerability and Transformation project (http://core.tdar.org/dataset/1582).

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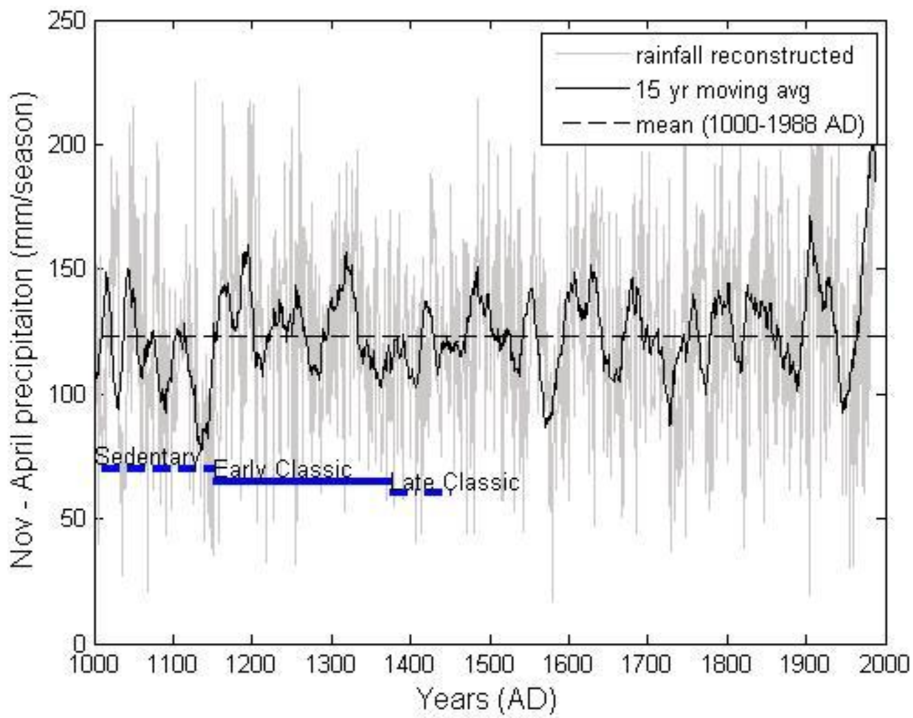

Fig. 12. Tree ring reconstruction of winter precipitation (mm season^{-1}) in southwestern Arizona, United States from 1000 to 2000 AD. Also shown are the three major eras of the Hohokam civilization and the mean of the time series over the entire period. Compiled from http://www.ncdc.noaa.gov/paleo/pubs/ni2002/az6.html, see also Ni et al. (2002).

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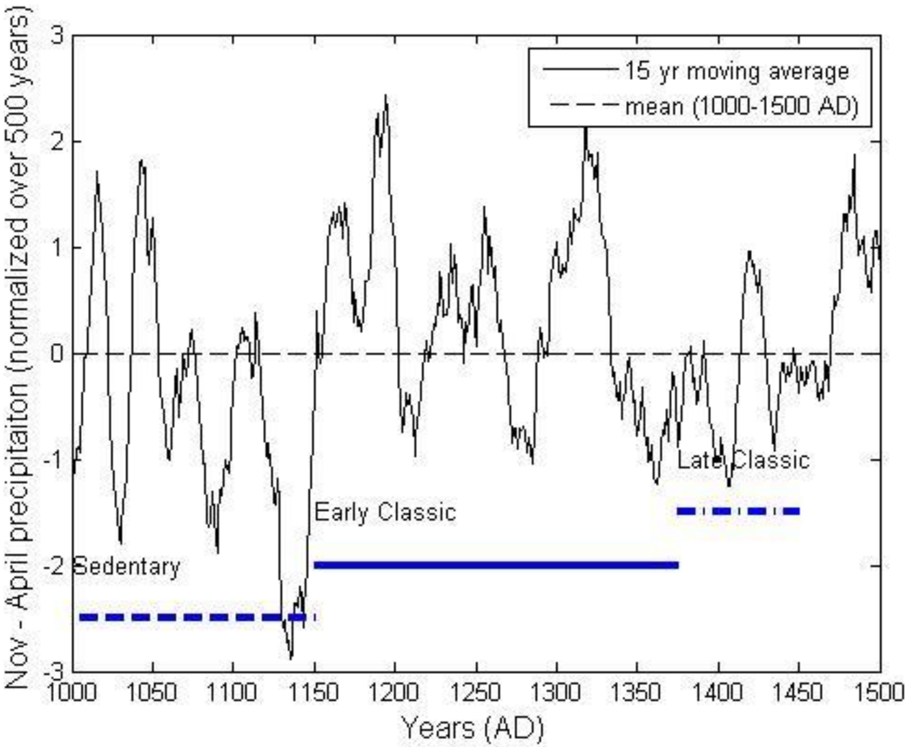

Fig. 13. The reconstructed and standardized (i.e. subtracting the mean and dividing by the standard deviation of the time series) winter precipitation (southwestern AZ, US) over the period of 1000–1500 AD. The sharp drop of 3 standard deviations in winter season precipitation is evident around the transition of sedentary to early classic Hohokam. Compiled from http://www.ncdc.noaa.gov/paleo/pubs/ni2002/az6.html, see also Ni et al. (2002).

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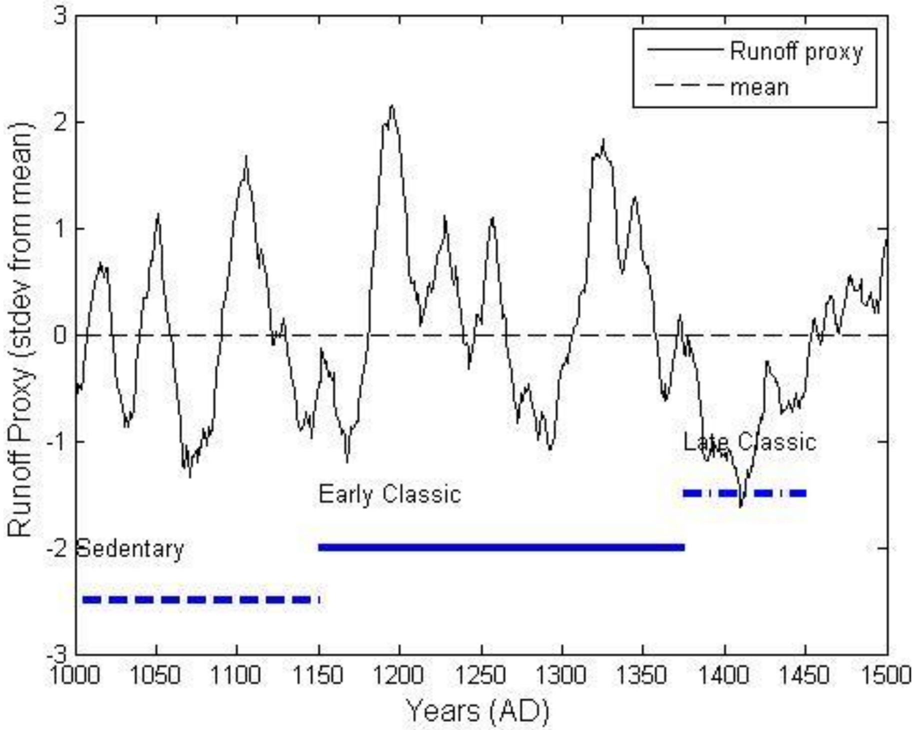

Fig. 14. A proxy for runoff conditions in the Hohokam. Obtained by subtracting reconstructed and normalized annual mean-maximum temperature from the reconstructed and normalized October through July precipitation for the southern Colorado plateau. The normalization is for the period between 1000 to 1500 AD. Compiled from Salzer and Kipfmueller (2005).