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Mid–late Holocene monsoonal variations from mainland Gujarat, India: A multi-proxy study for evaluating climate culture relationship

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ABSTRACT

A multi-proxy study involving palynology, phytoliths, sedimentology, clay mineralogy, carbon isotopes and magnetic mineralogy was carried out on Wadhwana Lake sediments from sub-humid zone of mainland Gujarat to determine the mid-Holocene climatic fluctuations, and its possible impact on the Harappan culture. The 1.03 m sediment profile of Wadhwana Lake shows five paleoclimatic phases. The study reveals high lake stand during Phase I (~7500–5560 cal yr BP). A considerable cool and moist climatic condition during Phase I is inferred due to the presence of pollen belonging to wet evergreen taxa and high phytolith climatic index 'Ic'. Later part of Phase I show gradual replacement of evergreen to deciduous pollen taxa, decrease in Ic value and dominance of smectite over kaolinite, indicating a reduction in wet climatic condition due to decline in the precipitation and prevalence of seasonally dry climate. However, a large variety of *Madhuca*, Meliaceae, Asteraceae pollen taxa, abundant fresh-water algae *Chrozophora* and Ceralia pollen in this period provides evidence of intensified arboriculture and agricultural activity. Low lake level and dry climate have been documented during Phase II (5560 to ~4255 cal yr BP) and are synchronous with the lake records of western Indian region. High values of phytolith aridity index Iph, high primary minerals, increase in the $\delta^{13}C$ values provide evidence for excessive dry climatic conditions at ~4255 cal yr BP. Phase III shows a gradual strengthening of SW monsoon after ~3500 cal yr BP. Phase IV shows a short pulse of dry climatic conditions (~3238 to ~2709 cal yr BP) followed by somewhat similar to present day climate for Phase V. The study concludes that onset of dry climate after 5500 cal yr BP is a regionally spread synchronous event that has been documented in several lake records of western India. It is surmised that the urbanization in Harappan civilization in North West India was coincident with the initial phase of declining rainfall of mid-Holocene. The emergence of cultural complexity of Harappan civilization should be seen as an initial adaptation to earliest phase of environmental deterioration and its subsequent decline is probably linked with the changing seasonality pattern and excessive dry climate of later phase (~4200–4255 cal yr BP) of mid-Holocene.

1. Introduction

The Asian summer monsoon system is known to determine the climate of the subtropics and tropics of South East Asia. The differential precipitation on the Indian peninsula is attributed to the receding SW monsoon from south to north and east to west. Though monsoon is a stable atmospheric phenomenon, considerable variability does exist in the spatial and temporal rainfall patterns. Monsoonal fluctuations can have devastating impact upon the human society over a period of time. Rapid environmental changes in the past have caused cultural changes, severe famine, and human displacements leading to collapse of ancient civilizations (see de Menocal, 2001; Weiss and Bradley, 2001; de Haug et al., 2003; Haberle and David, 2004; Wengxiang and Tungsheng, 2004). The onset of mid-Holocene aridity in the tropical and subtropical belts is attributed to the steepest decline of solar insolation at northern hemisphere around 6 kyr BP (Steig, 1999) causing major cooling of North Atlantic at 5.9 kyr BP (Bond et al., 1997). The synchronous records of environmental deterioration leading to widespread aridification post-6th millennia BP can be traced to the Afro-Asiatic monsoonal belt, currently the desert areas of North Africa, South Asia, and China. Hence, paleoclimatic records contradict the climate culture hypothesis as aridification in these regions preceded the cultural complexity in the ancient civilizations of mid-Holocene times (Brooks, 2006).

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The mid-Holocene climatic changes are coincident with the emergence of highly organized civilizations from the Afro-Asiatic monsoonal belt such as Egypt, Mesopotamia, Indus–Saraswati and in northern China regions that form the bulk of the deserts today (Brooks, 2006). Harappan culture during 5th millennium BP in NW India is one of the most extensively studied, highly urbanized civilizations of South Asia. Its archeological remains are widespread in the arid regions straddling the borders of India and Pakistan. Since this culture flourished along the Indus river valley, it is also referred to as the Indus valley civilization. The Harappan civilization, had its roots in earlier cultures. The earlier food producing communities (~9000 cal yr BP) established on the western highland of Baluchistan near Mehrgarh, later developed into village farming communities and pastoral camps (Possehl, 2002). During ~6300–5200 cal yr BP, further development in the agricultural practices and settled life led to the geographical expansion of what is known as the early Harappan communities that probably descended from the highlands to the plains of greater Indus valley. A rapid transition to urbanization during 4600–4500 cal yr BP resulted in a complex and stratified mature Harappan society with large urban centers (e.g. Harappa, Mohenjo-Daro, Kalibangan) mostly along the Indus and Ghaggar–Hakra rivers (Possehl, 2002). The post-Harappan phase (4200–3000 cal yr BP) saw the deurbanization of Harappan civilization that involved abandoning of urban cities and establishment of small village-like communities. Lothal, a major mature Harappan archeological site from Gulf of Cambay marks the southern most extent of Harappans in mainland Gujarat. Several post-Harappan sites can be seen i.e. Malvan near Surat and other adjoining areas. There are a number of post-Harappan sites near Orsang River close to Dhadhar.

Major urban settlements of Harappans near Indus and Ghaggar–Hakra river system indicate dependence of Harappan farmers on two water sources, local rains as well as river discharge. Two distinct sources of rainfall provide rains to north western region of India. Summer rains associated with the 'SW monsoon', were initiated by the seasonal northward movement of the Intertropical Convergence (ITC) due to warming of Asian continents during summer (Wright et al., 2008). Mid-latitude cyclones, that originate in the Mediterranean, travel eastwards across Southwest Asia and provide widespread winter rains to the north western part of India (Wright et al., 2008).

Decline of the Harappan civilization is often attributed to a regional weakening of Afro-Asiatic monsoonal climate of mid-Holocene. Considerable disagreement exists in the paleoclimate records of India and the emergence of highly complex Harappan culture. Harappan civilization was at its peak when large part of India was experiencing arid climatic conditions (Enzel et al., 1999; Gupta et al., 2003; Staubwasser et al., 2003).

The desert and desert margin areas of western India are sensitive to precipitation related to the subtlest climatic changes. Palynological proxies have long been studied to assess the climate–culture linked changes from sedimentary profiles of several lakes (Didwana, Lunkaransar, Sambhar, Nal Sarovar) from desert and desert margin areas of western Rajasthan (Singh, 1971; Singh et al., 1972, 1973, 1974, 1990; Prasad and Enzel, 2006). These authors argued that wet conditions due to higher winter precipitation during 6th millennia BP, were the cause of establishment of village farming and agricultural base to the Harappan culture. Decline of early Harappan communities in the plains of NW India during 4th millennia BP was due to weak monsoonal conditions (Singh et al., 1990). Precipitation reconstruction studies (Singh et al., 1972, 1974), were later modified through transfer function analysis (Bryson and Swain, 1981; Swain et al., 1983) provided better evidence of mid-Holocene aridity in western India, however, use of both uncalibrated and calibrated radiocarbon dates may have induced some error in age estimates in these studies (Madella and Fuller, 2006). Combined geochemical, sedimentological and palynological studies showed that fall in lake levels and desiccation preceded the de-urbanization or collapse of Harappan civilization (Enzel et al., 1999). Archeological studies, further questioned the climate–culture relationship (Misra, 1984; Ratnagar, 1987, 2000; Possehl, 1997a, 1999, 2002). However, shifting agricultural practices due to changing climatic conditions have been linked to the decline of complex society of Harappan culture (Madella and Fuller, 2006). Though the distinct changing pattern in the Harappan culture requires more careful study of the environmental deterioration, paleoclimatic studies so far do not satisfactorily explain the contradictory behavior of climate and Harappan culture flourishing at the same time. The stimulus propelling the widespread establishment of village farming of early Harappan community into a well-organized mature Harappan society with peak of urbanization, specialization in agricultural practices, water storage techniques, focussing human activity near river system and the rapid de-urbanization during later stages of 5th millennia BP (Possehl, 2002), needs to be investigated in detail.

Known paleoclimatic records are mostly from lake sediments of arid regions of Rajasthan (Singh, 1971; Singh et al., 1972, 1973, 1974, 1990; Bryson and Swain, 1981; Swain et al., 1983; Wasson et al., 1984; Rai, 1990; Rai and Sinha, 1990; Sundaram and Pareek, 1995; Kajale and Deotare, 1997; Deotare et al., 1998; Enzel et al., 1999; Roy, 2003). In contrast, apart from lake sediments from Nal Sarovar (Prasad et al., 1997; Prasad and Enzel, 2006) and estuarine sediments from Kothikhad (Prasad et al., 2007), which is in the lower reaches of Mahi River basin, about 60 km WNW of Wadhwana Lake meager information exists from mainland Gujarat, a major center of mature Harappa (Lothal). Dhadhar River, which flows through the central part of the mainland Gujarat, has been studied in detail by Rachna Raj (2004, 2007) and the major sedimentary facies of late Pleistocene deposits have revealed evidence of paleodrainages and provided important link between the sub-humid Narmada River basin in the south and semi-arid Mahi River basin in the north. The present study on the Wadhwana Lake adds meaningfully to the gap of knowledge which exists from mainland Gujarat, a major center of mature Harappa (Lothal).

We carried out multiproxy studies involving palynology, phytoliths, clay mineralogy, magnetic mineralogy and carbon isotopic studies from Wadhwana Lake sediments, located in a climatically sensitive region lying in the transitional climatic zones, sub-humid south and semi-arid north (Fig. 1A), showing better sensitivity to even minor changes in temperature and precipitation. Being located in the central part of the mainland Gujarat, this lake is ideal to document and assess the mid–late Holocene precipitation related changes for the regional correlation as well as to evaluate the climate culture relationship.

2. Location and climate

On the basis of average rainfall, the Gujarat region has been climatically divided into humid, subhumid, semiarid, arid and extremely arid zones (Fig. 1A). Dhadhar River basin lies in the transitional area of sub-humid and semi-arid climatic zones towards south and north respectively (Fig. 1A), where the average annual rainfall varies from 800 mm to 1400 mm. Dhadhar is an independent river which originates near Shivrajpur at 22°30′N latitude and 73°45′ E longitude in the Aravalli range, and flows between two main rivers of mainland Gujarat i.e. Mahi River to its north and Narmada river to its south and debouches into Gulf of Cambay (Fig. 1B). It shows broad estuarine the mouth, with the width of estuary being ~5 km (Fig. 1B). It has several small tributaries (Vishwamitri, Bukhi, Ranghav, Rupa, Khadi etc.) that are only active during monsoon months. In the area between Dhadhar and Orsang Rivers, a number of lakes and ponds have been reported (Rachna Raj, 2004). The IRS FCC imagery of the area between Dhadhar and Orsang also shows traces of paleochannels, cut off meander, meander scars, ox-bow etc. This indicates that the ponding in this region is due to channel shifting, probably as a result of uplift along Orsang fault in the east