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Implications of palaeohydrological proxies on the late Holocene Indian Summer Monsoon variability, western India

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ABSTRACT

In this paper we identify changes in the Indian Summer Monsoon (ISM) intensity during the late Holocene as revealed by palaeohydrological proxies in the fluvial archives of western India. Proxy indices, including the geomorphological, sedimentological, geochemical and biological evidence along with chronology have been employed to highlight the trend in ISM intensity over the late Holocene. It is inferred that on a longer timescale, the Indian Summer Monsoon weakened during the late Holocene however; short pulses of ameliorated monsoon occurred around 3, 1.6 and 0.3 cal ka BP. Clustering of flood events is seen to occur at 3–2.8, 2.2–1.6, 1.3–1.1 and 0.65–0.2 cal ka BP not necessarily coinciding with strengthening of the ISM. Palaeoflood data with regard to the ISM variability shows that the two most prevalent flood events at 0.5 and 1.7 cal ka BP coincide with the weak monsoon period/climatic transition in this region. The occurrence of high magnitude flood events during weak monsoon periods is also reflected in the modern flood and rainfall data. It is surmised that high magnitude flood events may represent peak monsoon periods however, cannot be singularly considered as indicators for enhanced monsoon conditions in a region. Only a more robust database of palaeohydrological proxies can further validate their implications on the monsoonal changes over western India.

1. Introduction

The Indian Summer Monsoon (ISM) forms an important component of the global climate system involving coupled atmosphere-land-ocean interactions (Webster et al., 1998). Extreme floods and droughts, affecting a large population in South and East Asia, are caused due to the variations in monsoon intensity, making it imperative to have a robust monsoon prediction system. An understanding of the past variations in the ISM pattern, intensity and frequency is however critical for prediction of regional monsoon precipitation. Hydrological response to climatic variability, especially during the last millennium is particularly important for understanding recent and future environmental change in a region (Benito et al., 2015). This period was globally characterized by Little Ice Age (LIA) cooling between AD 1400 and 1850 and the Medieval Warm Period (MWP) warming between AD 900 and 1300 (Mann, 2002a, b) making it increasingly important to decipher the signals of hydrologic change. In fluvial systems, the hydrological changes are marked by variations in the discharge regime or magnitude. The reconstruction of palaeohydrological changes provides not only an insight into the past environmental changes but has application for sustainable use (Hoek, 2012).

As for India, the Indian Summer Monsoon is the key system controlling the hydrologic regime of the water resources. In the last few decades the continental and marine proxy records from the Indian subcontinent have provided evidence for past changes in monsoon dynamics (Gupta et al., 2003; Sinha et al., 2007; Chauhan et al., 2009; Prasad et al., 2014). Palaeohydrological proxies form one of the important databases for monsoon reconstruction. The alluvial archives in western India provide scope for such an application. The monsoon change histories from the alluvial deposits of various river basins have been previously developed with a chronological outline (Chamyal et al., 2003; Juyal et al., 2006; Kale, 2007; Sukumaran et al., 2012) followed by site-based flood chronologies from slackwater deposits in the alluvial and bedrock rivers in recent times (Kale et al., 2003; Sridhar, 2007a; Sridhar et al., 2014, 2016). A broad understanding of the monsoonal variations based on a number of palaeohydrological studies from the river basins of western India has been attempted, but the temporal and spatial pattern of changes in monsoon with regard to the hydrological regime is not well established. This paper provides a synopsis of the evidence of ISM variations recorded in the

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palaeohydrological proxies from the existing database and highlights their relevance to the larger climate change scenario especially during the mid to late Holocene.

2. Background and concept

The main focus of the present study is the west-flowing rivers of Mainland Gujarat in western India (Fig. 1). Mainland Gujarat refers to the region of Gujarat state stretching between the Aravalli mountain ranges in the north and the Satpura ranges in the south, separated from the Kachchh and the Saurashtra Peninsula to the east. The lithology of the region comprises the Deccan Trap basalts, the rocks of the Aravalli super group viz. phyllites, schists, quartzites, ultramafics, granites and gneisses and the Quaternary sediments. A large part of mainland Gujarat is occupied by the Alluvial Plains (Merh and Chamyal, 1997). The channels are deeply incised either in bedrock or alluvium, and even high flows are insufficient to fill the whole channel (Gupta, 1993). The major rivers that flow through this region are the Sabarmati, the Mahi, the Narmada and the Tapi, all of which originate in the neighbouring highlands and flow from east to the west, debouching into the Arabian Sea. The Sabarmati and the Mahi river basins are situated in the semi-arid climatic zone, whereas the Narmada and Tapi fall in the subhumid climate zone (Fig. 1). The discharge in these river basins is related to the SW monsoon and the passage of monsoon depressions and low pressure systems, either from the Bay of Bengal or the Arabian Sea. Large floods have been recorded on the Mahi, Sabarmati and the Narmada Rivers (Dhar and Ghose, 1972; Kale, 1999; Goswami et al., 2006; Krishnamurthy et al., 2009) during the last few centuries. The river channels are bounded by Pleistocene terrace sediments forming 30–40 m high cliffs that provide resistant boundaries and restrict floodplain widths, channel migration and splay formation. Assuming that the extent of the river basin has remained essentially constant since the early Holocene, the changes in channel morphology are largely the product of climatic variations and associated variations in flow regime.

Alluvial sedimentary records are the archives of river response to periods of higher and lower discharge. Palaeohydrological interpretations concerned with the reconstruction of past river flows, average flows of low to moderate magnitude and frequency, or infrequent high magnitude events, are possible. The latter are commonly reconstructed in the bedrock settings using slackwater deposits and other palaeostage indicators (Baker, 1987), whereas the discharge estimations of average flows is based on the palaeochannel dimensions and sedimentological characteristics in the alluvial reaches (Patton, 1988; Reinfelds, 1995). Earlier studies using palaeohydrological techniques have revealed phases of hydrological change in the rivers of mainland Gujarat (Sridhar, 2007a, b, c; Sridhar and Chamyal, 2010; Sridhar et al., 2014, 2015, 2016). Also, several geomorphological, sedimentological, geochemical and biological evidence for hydrological changes have been observed in the sediment archives. Since hydrological changes are directly related to the variations in the ISM intensity in this part of the subcontinent, we synthesize the published palaeohydrological proxy data from the alluvial river basins to decipher the past variations in ISM. Using chronology of the palaleoflood events and ages from the other alluvial terrace records, a broad-based correlation between hydrological changes and ISM variations during the late Holocene is attempted. Major clustering of flood events and the phases of weak and enhanced monsoon have been identified on the basis of the summed probability distribution (PDF) plots created using OxCal v4.3.4 (2013) software. Frequency plots have also been derived for flooding events in the Mahi, Narmada and Sabarmati River basins during the late Holocene and have been compared with the other multi-proxy marine and continental data. A total of 26 radiocarbon and 4 OSL dates (Table 1) have been used to generate the frequency plot for the flood events and periods of weak and enhanced monsoon of which 15 calibrated ages have been used for the PDF plot. To further test the observations on the implications of palaeohydrological proxies on past south west monsoon variability in western India, an analysis of modern flood and precipitation record in the three river basins has been carried out.

3. Palaeohydrological proxies

3.1. Geomorphological evidence

The palaeohydrological evidence provided by the geomorphology is often expressed as forms in the landscape pointing towards the past activity of a geomorphic system (Hoek, 2012). Such geomorphic features include the river terraces, abandoned channels, meander loops and changing channel patterns. The geometrical parameters of channels such as width, depth, radius of curvature and meander wavelength are important palaeohydrological proxies. Based on these parameters, the palaeodischarge of channels can be estimated from established morphologic or hydraulic relations (Williams, 1988) and can

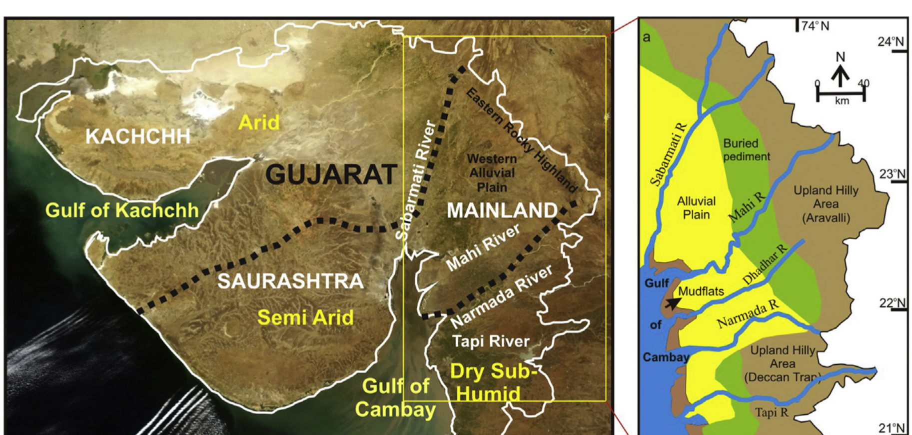

Fig. 1. Map showing the physiographic divisions of Gujarat, the climatic zones and major rivers of Mainland Gujarat. (a) Major geomorphic zones of Mainland Gujarat (modified after Sridhar and Chamyal (2017).