Evidence of a late-medieval mega flood event in the upper reaches of the Mahi River basin, Gujarat

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Palaeoflood records are of great significance in revealing the magnitude and frequency of large floods and thus the past monsoon conditions. The Mahi River, one of the major west-flowing rivers of India controlled by the southwest monsoon has preserved deposits of past floods dating back to 5 ka. A flood deposit emplaced by a mega flood event with discharge ~7300 m$^3$/s$^{-1}$ has been found at Diapattan in the upper reaches of the Mahi River basin. Based on the pottery available at the site, the event can be said to belong to late-medieval time. The timing of this mega flood event recorded at Diapattan in the Mahi River basin and records of the adjacent river basins suggest that this event represents the strengthened monsoon during the Medieval Warm Period (900–1400 AD). There exists a correlation between the extreme hydrological events in the Mahi, Narmada and Tapi river basins and this can be attributed to a regional monsoon domain.

Keywords: Mega flood event, monsoon, palaeofloods, pottery.

The southwest (SW) monsoon controls the rainfall supply to the west-flowing rivers in India. As the flow of these rivers changes only as a consequence of rainfall variation, the flood records provide information about the SW monsoon conditions. Historical and palaeoflood data are an important source of information for establishing the magnitude and frequency of extreme floods that have occurred prior to the instrumental period. The magnitude and frequency of large floods are precisely known for the period of gauge and historical records, but information on earlier floods is lacking. The sediment records of the large-magnitude floods are selectively preserved, whereas deposits from smaller floods are more likely to be removed by subsequent erosion due to their proximity to the active channel. The availability of any palaeoflood record is therefore of significance in revealing the past monsoon conditions. The Narmada, Tapi and Mahi are the three major west-flowing rivers with a long palaeoflood history. Whereas the Narmada and Tapi are considered to be tropical rivers, the Mahi is a sub-humid to semi-arid river. However, the flood history of these rivers appears to be comparable and the extraordinary peak flood events dating back to late Pleistocene have been inferred in the

8. Intek Resources, A world class Ni-laterite project in the Philippines, A scientific brochure issued at the 32nd IGC, Philippines Resources Inc., Oslo, 6–14 August 2008, p. 124; www.intekresources.com

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Narmada and Mahi. Records of early Holocene flood events have been found in the Tapi basin and those of mid–late Holocene have been preserved in the Narmada and Mahi. In the present communication, a mega flood event has been reported from the upper reaches of the Mahi River basin. An attempt has been made to discern as to whether this event was the result of a short surge in an arid climatic regime or a part of an ameliorated monsoon.

The Mahi River (583 km in length and 34,842 km² in drainage surface) originates from the Mahi Kanta hills in the Vindhyachal range of Madhya Pradesh, entering the sea at the Gulf of Cambay (Figure 1). The lithology comprises metamorphic rocks of Aravalli Super Group, the Deccan Traps, and the alluvial deposits of Pleistocene and Holocene age. Whereas the main channel on the convex banks is bounded by cliffs rising about 30–40 m from the river level, it is flanked by floodplains and point bar deposits on the concave banks. The sediments comprising these cliffs are deeply incised inland forming ravines.

Climate in the Mahi River basin today is sub-humid to semi-arid with warm wet summers and cool dry winters. The area receives monsoonal rain and the mean annual rainfall decreases from 850 mm in the headwaters to 600 mm in the lower reaches. Mean annual run-off is ~135 mm and the mean annual discharge is 384 m³/s. Majority of the rainfall occurs in association with the passage of monsoon depressions and low pressures, either from the Bay of Bengal or the Arabian Sea. The Mahi basin falls within the zone of heavy rainfall associated with disturbances from the depressions and cyclonic storms arising in the Bay of Bengal. During the 80-year period from 1891 to 1970, 49 monsoon depressions traversed through the basin out of which 44 originated from Bay of Bengal and the remaining 5 from the Arabian Sea. The flood-generating conditions in the Narmada and the Tapi basins are also related to the Bay of Bengal depressions and cyclones.

The flood events that occurred in the past have deposited sediments along the channels at different elevations in all the river basins. Flood-generated, poorly sorted sediments comprising coarser clasts are referred to as flood deposits. Unconsolidated sands and silts that accumulate relatively rapidly from suspension during major floods, particularly where flow boundaries result in markedly reduced local flow velocities are described as slackwater deposits (SWD). The most common sites of deposition and subsequent preservation of slackwater deposits are the tributary mouths, channel-margin alcoves, caves and rock-shelter deposits. The local hydraulic conditions at these sites result into a drop in the flow velocity and deposit flood sediments. Interestingly, in the Mahi River basin the dissections in the ravines provide an ideal site for backflooding of the freshwater from the main channel and accumulation of slackwater sediments. These are deposited much inland and at elevations of up to 20 m above the river level and are protected from the annual flooding of the channel as well as any other minor flood events, since their deposition and records of flood events dating back to ~4.5 ka have been documented in the downstream alluvial reach.

Flood deposits have also been identified in the upper reaches of the Mahi River near Diapattan. The Panam River, a tributary, meets the Mahi, ~2 km downstream of the site (Figure 1b). The Mahi channel meanders further upstream into convex and concave bends. The convex meander bend is bounded by the highly dissected Pleistocene sediment cliffs. The precedent concave bend is characterized by the Holocene valley-fill terrace sediments. The slackwater deposits are exposed at an elevation of ~9 m above the river level and ~200 m inlandward in the ravines (Figure 1b). The sediment succession ~1.5 m thick comprises of alternate horizons of poorly laminated silt and clay (Figure 2c) inset into the older gravel and sand/silt sequence, which may well be contemporaneous to the upper fluvial sequence described by Juyal et al. dating back to ~30 ka. Further upstream, in a small ravine cutting are exposed a thick pile of sediments (Figure 2a, A) comprising fine sand, silt with embedded gravels and pebbles. Moreover, these sediments also contain large amount of artefacts, including bricks, roof tiles and pot

Figure 1. a, Location of the flood deposit site in the Mahi River basin. b, Geomorphologic map of the study area showing the placement of flood deposits in the ravines near Diapattan.
shards, spread over ~2 km along the river channel and up to 1 km inland and are seen exposed at several sites along the river channel and gullies. At location A, the flood deposits are seen resting on a 1 m thick massive silt horizon and overlain by a metre thick finely laminated silt with small fragments of pottery. The section at location B (Figure 2 b, B) comprises ~2 m thick flood deposit horizon overlain by an equally thick horizon of finely laminated silt with small pottery fragments. The pottery occurring within the flood deposits is most predominantly grey and black ware comparable to samples reported by Subbarao\textsuperscript{9} in the excavations at Baroda. The pottery (Figure 3) includes pot shards with carination and incised decoration at the shoulder, top finials of the lids, pieces of big jars and bricks\textsuperscript{9} belonging to later 15th century to early 16th century AD. The archaeological evidence points to the fact that the old town of Diapattan might have been buried under flood deposits during a high-magnitude event a little later.

The same event has also been recorded in the slackwater deposits in the adjacent ravines due to back flooding. The occurrence of these SWDs inset into the late Pleistocene sediment cliffs also suggests that Diapattan may have been located on the top of these cliffs at an elevation probably not reached by smaller and more frequent flood events. It appears that the flood event recorded at Diapattan was one of the very high-magnitude events on the Mahi River during historic times. However, in the absence of past stream-flow records, the associated discharge is not known. An attempt was therefore made to estimate the discharge associated with these flood deposits using the step-backwater modelling technique\textsuperscript{10}. Such palaeo-discharge estimations require stable boundary conditions, restricting their use to bedrock reaches of the rivers. In the study area, however, the Pleistocene sediments which occur as high cliffs at one bank and the rock exposures on the other provide resistant flow boundaries, not allowing the frequent shifting of banks over a broad range of flow conditions. Estimation of the palaeoflood discharge associated with these deposits has been carried out using HEC–RAS one-dimensional hydraulic model. Modelling was carried out for the reach of about 5 km with four cross-sections, the palaeoflood site being located almost in the centre. A rating curve was generated for the available peak discharges at the nearby gauge stations and the discharge associated with the palaeoflood deposits was estimated accordingly. The results suggest that these flood deposits were emplaced by flows that were at least 7300 m$^3$ s$^{-1}$. Long-term discharge gauge data are not

**Figure 2.** A profile along $AY$ exhibiting the geomorphic set-up and overall stratigraphy of the study area. a. View of flood deposit with bricks and potshards at location A. b. View of flood deposits with pebbles and pottery at location B. c. View of slack water sediments in the ravines at location C. A and B are the lithologs at locations A and B respectively.

**Figure 3.** A view of artefacts found embedded in the sediments at Diapattan. (a) A potshard with incised decoration, (b) the top finial of a lid and (c) part of a brick.
available in the study area for a ready comparison. However, the highest discharge recorded at Paderdibadi (upstream) was 1122 m$^3$s$^{-1}$ in 1997, 22,000 m$^3$s$^{-1}$ in 1990 (downstream) at Khanpur and 3419 m$^3$s$^{-1}$ at Chakalia on the Anas River, a tributary which meets the Mahi upstream of Diappattan.

This high-magnitude flood event probably occurred about 500 yrs BP when the climatic conditions were much different from the present. Palaeoflood record in the lower reaches of the Mahi River has indicated repetitive flooding in enhanced monsoon conditions during the early phase of the mid–late Holocene and periodic flooding during weak monsoon$^7$ at about 1.7 ka. Slackwater palaeoflood hydrology indicates$^{11}$ distinct periods of large and moderate floods in central and western India during the last 2 ka. Flood records$^8$ from Narmada and Tapi River basins in western and central India suggest a dry period between 2200 and 1700 cal. yrs, followed by a strengthening monsoon regime until 500 cal. yrs. Moderate to high floods have also been documented between 1 and 0.4 ka and low floods between 0.4 and 0.2 ka in the arid Luni River basin$^{12}$. The sediment archives of the arid Penner River in southern India also indicate amelioration in the monsoon since 3–2 ka, followed by weakening of the monsoon between 2 and 1 ka and stronger SW monsoon during the medieval warming from 1 to 0.6 ka, followed by the arid phase related to the Little Ice Age (LIA)$^{13}$ between 0.6 and 0.2 ka.

The modern gauge records have also shown that the large flood events that occurred during the last 50 years, viz. 1959, 1968, 1970, 1973, 1981, 1987, 1991, 1996 and 2006 on the Mahi, Narmada and Tapi, though with different magnitudes, were synchronous. Also the mid–late Holocene flood deposits from the Mahi and the Narmada have yielded similar dates$^6$. The historic palaeoflood records are well documented in the adjacent river basins of Narmada and Tapi, and reveal the absence of large-magnitude floods during the LIA. However, a catastrophic flood has been recorded on the Tapi River at the beginning of the LIA$^1$. Flood deposits dated to 300–450 yrs BP have also been recorded at various sites in the Narmada$^{11}$. From the time-frame of occurrence (late 14th to early 15th century) of this high-magnitude flood event recorded at Diappattan in the Mahi River basin and from records of the adjacent river basins, it can be inferred that this event represents the strengthened monsoon during the Medieval Warm Period (AD 900–1400). Also, there exists a correlation between the extreme hydrological events in the Mahi, Narmada and Tapi river basins which can be attributed to a regional climatic domain.


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