Flooding of the Indus River in 2010: How it changed the landscape?

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Introduction

The Indus River in Pakistan has been heavily engineered for centuries, comprising one of the largest irrigation networks in the word to meet water needs. As a result the current outflow is reduced to ~10-27% of its historical value (Asif et al., 2007), and the river runs dry at the river mouth multiple months every year. Emplacement of dams, reservoirs and water diversion structures reduced sediment load to the ocean by an order of magnitude.

The July-November 2010 flood (recurrence interval of ~30 years) inundated nearly 40,000 km2 of the 970,000 km2 large basin, during which 20 million inhabitants were displaced for weeks to months and close to 2,000 fatalities were reported (Syvitski and Brakenridge, submitted).

Fig. 2. Analysis of Reflectance Thresholds
Four different reflectance values were tested to optimize a reflectance threshold value for sediment deposition (LANDSAT 5, band 5).

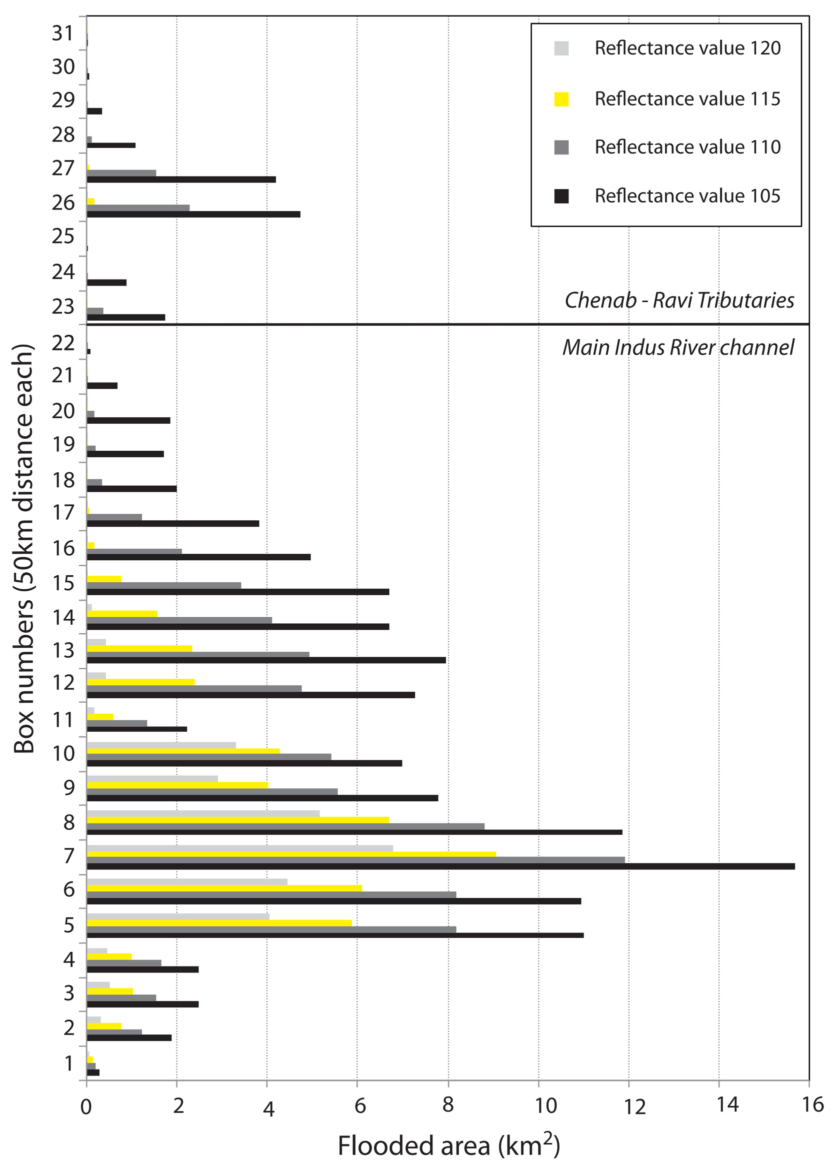
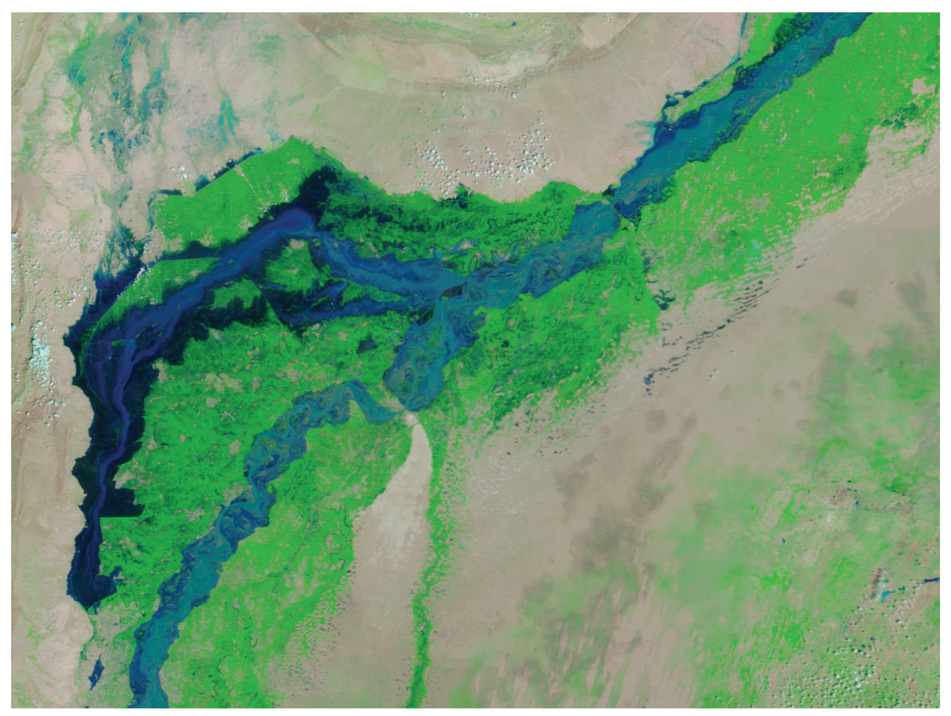


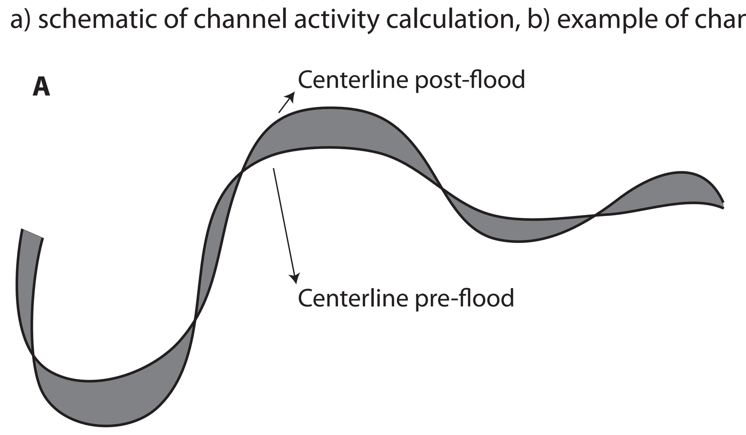
Fig. 1b. Overview of the flood extent
The breach at segment 11 is clearly visible, showing that a major part of the floodwater is diverted east of the actual river channel.



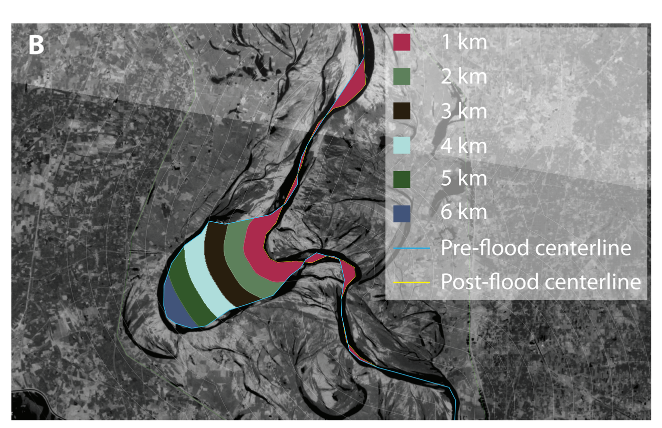
Methods

We analyzed changes in LandSat 5 TM (Band 5, 1.55-1.75nm) reflectance (Fig. 2) to map the effects of the Indus flood wave on the main channel, and determined the spatial distribution of sandy flood deposits along ~1500km of river length. Different reflectance coefficients are examined to optimize the threshold reflectance value to distinguish unvegetated sandy deposits (Fig 2). We can only map sand extent, and have no estimate of sediment thickness. Channel migration patterns were determined by mapping the pre- and post-flood centerline of the main river channel and are expressed as 'channel activity' (see Fig 3). Furthermore, relations between assumed control parameters (slope, sinuosity, distance to centerline) and the extent of flood deposits and channel migration are analyzed.

Fig. 3. Channel activity
a) schematic of channel activity calculation, b) example of channel activity due to the Indus 2010 flood event.



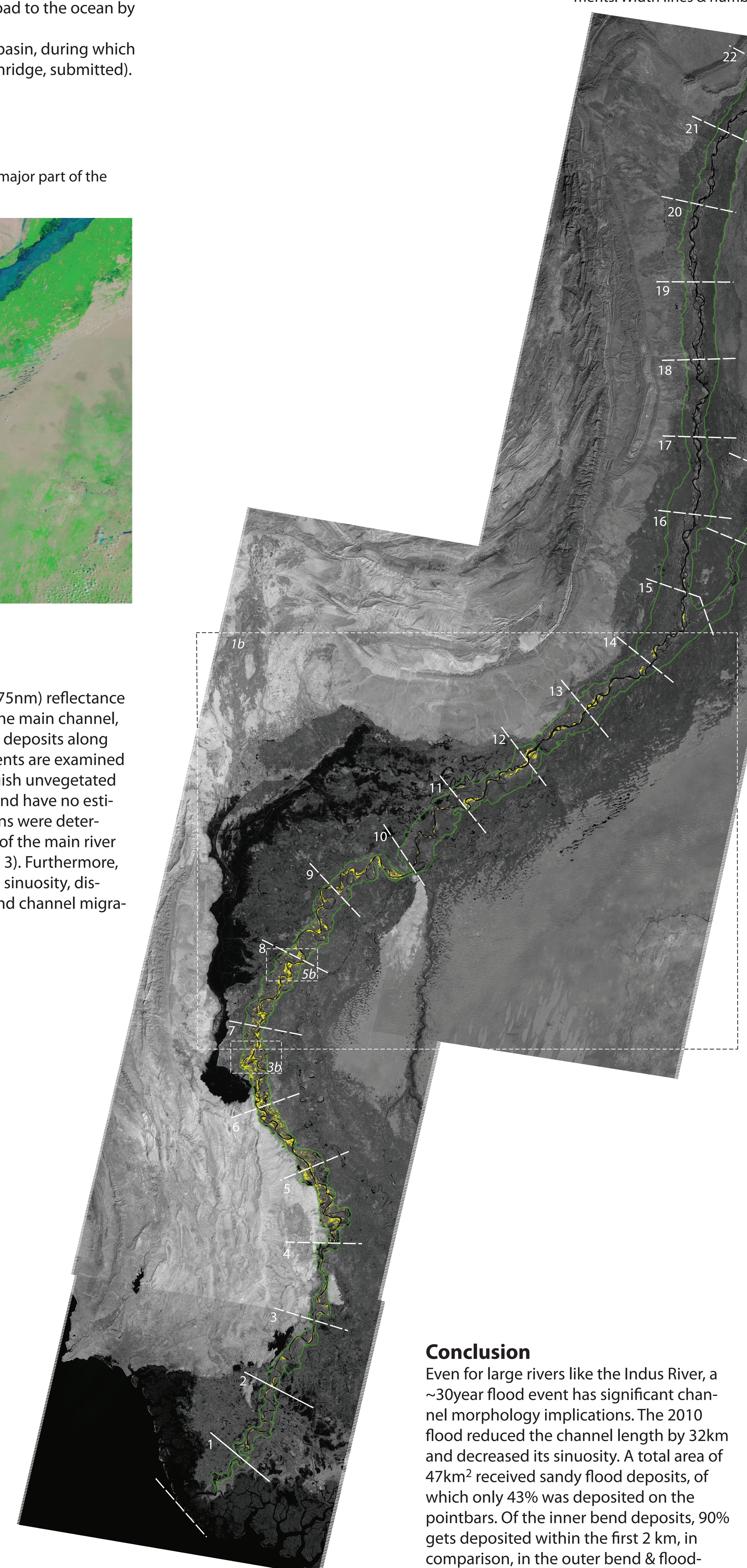
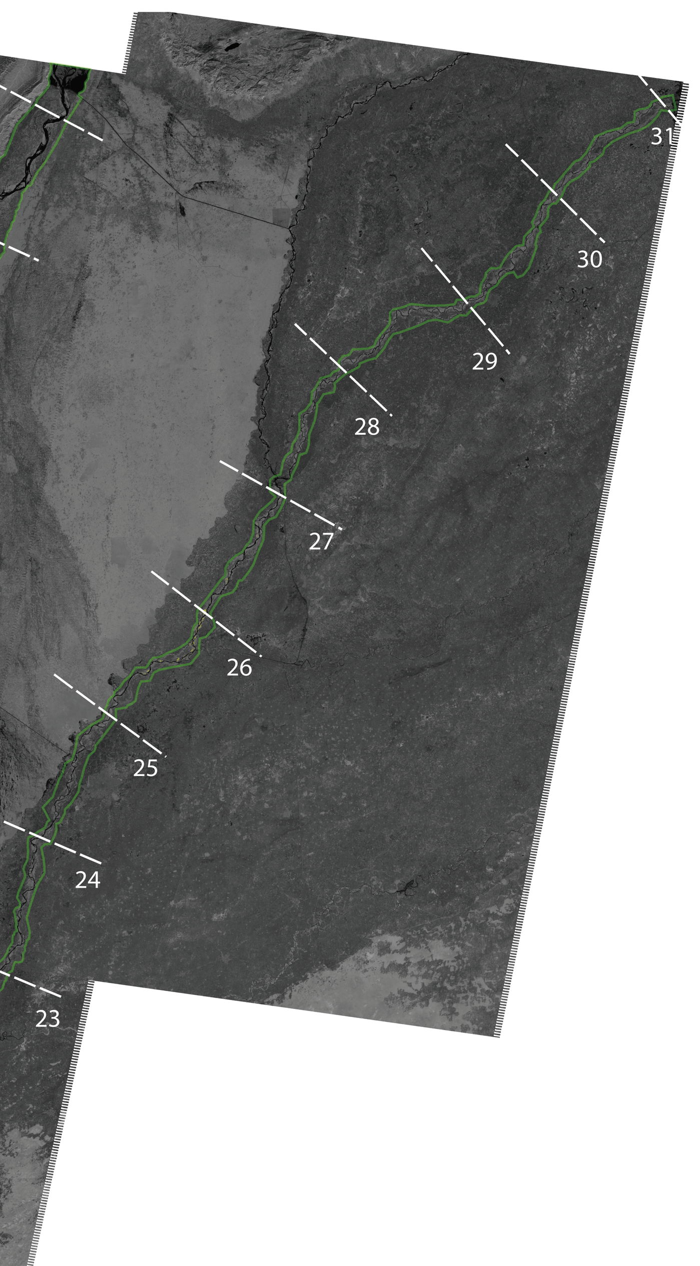
Channel activity = (Shaded area) / (Length of pre-flood centerline)
Flood event



References

- Asif, I., Clift, P. D., Giosan, L., Tabrez, A. R., Tahir, M., Rabbani, M. M., and Danish, M., 2007. The Geographic, Geological and Oceanographic Setting of the Indus River, in Gupta, A., ed., Large Rivers: Geomorphology and Management, John Wiley & Sons, Ltd, p. 14.
- Syvitski, J.P.M., and Brakenridge, G.R., submitted. Causation and Avoidance of Catastrophic Flooding along the Indus River, Pakistan, GSA bulletin.

Fig. 1a. Study area overview
LandSat 5 imagery, December 2010 (post flooding). Green lines mark the active floodplain during the flood event. Yellow dots are areas interpreted as fresh deposited sediments. Width lines & numbers reflect 50km sediments.

Conclusion

Even for large rivers like the Indus River, a ~30year flood event has significant channel morphology implications. The 2010 flood reduced the channel length by 32km and decreased its sinuosity. A total area of 47km² received sandy flood deposits, of which only 43% was deposited on the pointbars. Of the inner bend deposits, 90% gets deposited within the first 2 km, in comparison, in the outer bend & floodplain, 80% gets deposited within 4km.

Fig. 6. Channelbelt Slope controls Sediment deposition

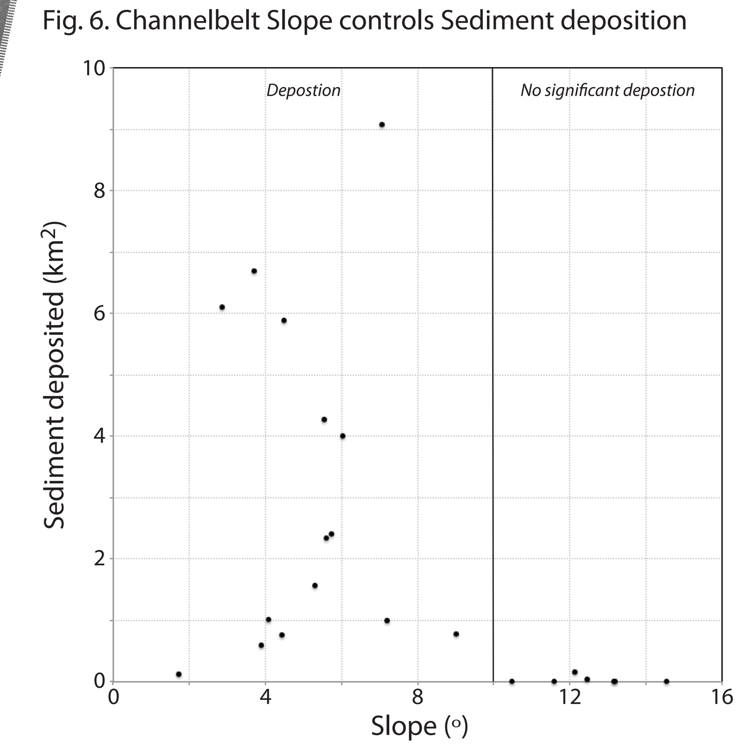


Fig. 4. Longitudinal sediment deposition pattern for all deposited sediment and its distribution between the inner-bends and outer-bends in respect to channel activity.

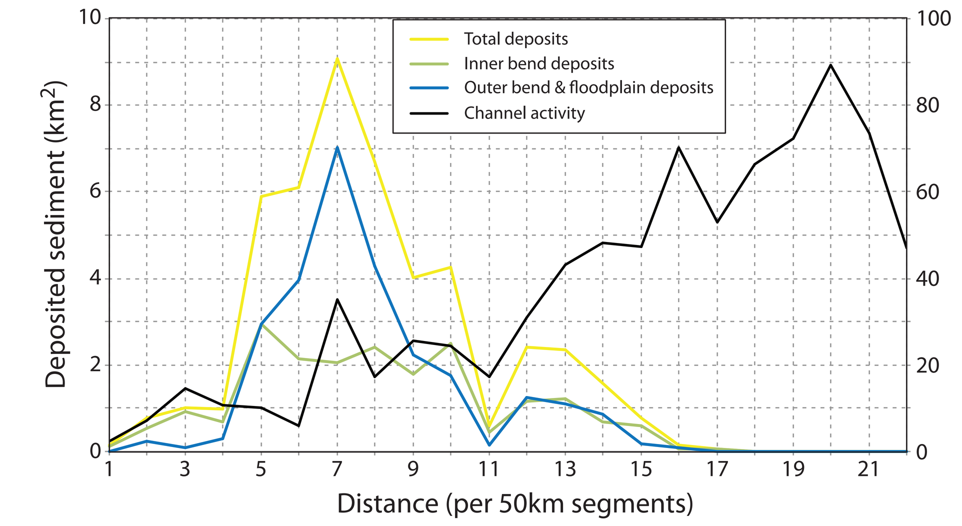
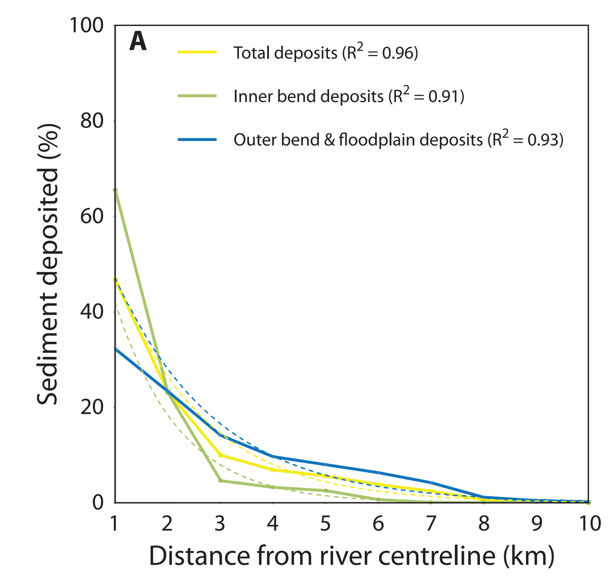
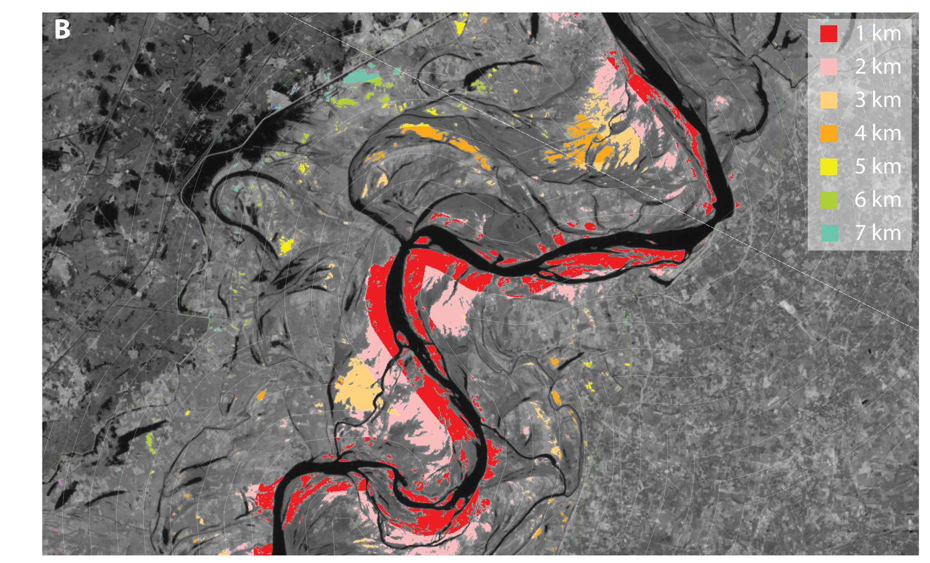


Fig. 5. Lateral distribution of deposited sediment, a) showing the difference between lateral sediment distribution between inner bends and outer bends & floodplain deposits, b) an example of lateral sediment distribution.





Results

Most flood sediment is deposited within the lower stretch of the Indus River where the Chenab tributary joined the Indus River, but above the deltaic area (between segment 4 and 15) (Fig. 4).

1) Channel migration

The mean rate of channel migration along a river reach can be expressed by channel activity (Shields et al., 2000), Fig. 3a. Over the analyzed course (pre-flood length: 1567 km) the Indus River became 32km shorter and sinuosity decreased from 1.40 to 1.38 (68% of the 22 segments experienced a decrease in sinuosity). Channel activity is the highest in the upper part of the Indus River (50 – 90 m / flood event) compared to the lower stretch (5 - 35 m / flood event). Only one single large channelbend was cut off, reducing the channel length by ~13km (Fig. 3b).

2) Lateral sediment deposition

Only 43% of the total deposited sediment was deposited in the inner bends of the river, Most of this classic point bar accretion (~90%) occurs within 2km of the channel centerline. Crevasse splaying is widespread and remarkably extends further away from the centerline, only 32% of the sediment is deposited within the first kilometer, ~80% within 4km. Overall, 82% of the total deposited sand (47km2) gets deposited within 1km of the channel centerline (Fig. 5).

3) Morphological changes & control parameters

Channelbelt slope controls deposition rates, where significant deposition only occurs at slopes below a 10° threshold. (Fig. 6). Channel activity, i.e. erosion, is negatively related to both sinuosity and sediment deposition (when excluding the deltaic area and 2 river segments where a) the flood breached the channel and b) the breached water joined the Indus River again) and positively related to slope (Fig. 7).

Fig. 7. Sinuosity and Slope are negatively correlated with Channel activity. Whereas there is a positive correlation between sediment deposited and Channel activity.