ABSTRACT

The spatio-temporal variability of river processes, namely erosion and deposition is governed by the balance between basin scale sediment supply and the reach scale channel transport capacity. This balance is being altered by rampant sediment mining from the rivers, leading to river bed incision, lateral channel instability and loss of instream and riparian habitat. The sediment mining guidelines for Indian rivers are based on empirical approaches, and do not consider the variability of river processes at various spatial as well as temporal scales. As the overall river condition across the globe is declining, there is an urgent need for a sustainable approach to sediment mining. In this study, we adopted a multidisciplinary approach to develop a framework for sustainable sediment mining, in order to maintain the river in a good health. We were able to identify the specific river reaches for sustainable sediment mining on the basis of spatio-temporal variability in sediment budgeting and morphological diversity. Hydrological data (1987-2015) and remotely sensed satellite imagery were also applied to examine the degree of alteration in channel morphology in response to changes in river processes. We further applied the SWAT hydrological model to inspect the suitability of a watershed modelling approach for sediment budgeting in a large river basin.

The mainstream of the Narmada River basin was divided into seven reaches of length 100 km-200 km, based on the sites of eight gauging stations indexed as N1-N8. We found that upstream subbasins, with high local relief and steep hillslopes were characterized with the highest values of sediment yield, and hence the sub basins N1, N3 and N4 were identified as the major sediment source regions. We also established that the empirical relationships used by the Indian agencies consistently underestimate the sediment yield values.

The application of SWAT model for the Narmada River basin was found to be suitable to analyze water and sediment distribution, except for sub basins where hill slope mass wasting processes might dominate. The calibration of SWAT was performed using SWAT-CUP and we found that more than 40% of the measured data was bracketed under the 95PPU envelope, for both calibration and validation periods. Particular mainstream reaches with lengths ranging from 1 km to 100 km were identified as deposition dominated, though the monthly variability of river process was consistent.

Based on the reach scale sediment budget, it was observed that reaches N3-N4, N5-N6 and N7-N8 were dominatingly aggrading up to 300 MT over the 29 years of study period. The sediment budget analysis suggests that a coupled interaction of sediment yield and stream power explained the spatial variability in river processes. A positive relationship between volume of sediment erosion and the reach scale stream power was obtained, exceptions were the reaches with limited upstream sediment supply. Yet, there was an inherent temporal variability in the river processes. The threshold for river aggradation processes was estimated to be ~1.5 g/l sediment concentration. The temporal change in reach scale morphology reflected the trend in river process, that is, for a month of active degradation, a decrease in areal extent of channel bars was observed. However, there was a discrepancy in the mass of sediment degradation and the decrease in areal extent of channel bars in all cases, especially the upstream reaches, and this suggested that most of the sediment reworking might be occurring in the vertical dimension.

Hence, based on the above understanding, we recommended that bar skimming should be the dominant mode of sediment extraction, rather than instream pit mining, which may lead to major changes in the channel cross sections. Deposition dominated reaches identified based on the hydrological data analysis as well as the SWAT-based analysis were recommended to be targeted for sediment mining activities. Further only those point bars should be selected for sediment extraction which are actively aggrading. The mass of sediment extraction should be less than the mass of sediment aggradation for the particular reach. This information was gained by mapping the reach wise morphology of the Narmada River. For example, for the 100 km reach N3-N4, the rate of sediment aggradation was ~7 MT per year (200 MT over 29 years), which implies that not more than 7 MT sediment should be extracted from the reach in a year. Further, the threshold for river aggradation process of ~1.5 g/l should also be taken into consideration. Such measures of sustainable sediment mining are essential first steps to ensure healthy structure and functioning of the river and maintenance of the river ecosystem.