Study of river sensitivity for sustainable management of sand quarrying activities in Damodar river, West Bengal, India

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For sustainable management of a threatened river, a process-based understanding as well as in-depth study of the river is required. Unfortunately, during Anthropocene almost every river in the world is under threat. Damodar river, an important drainage system of the Bhagirathi–Hooghly river basin situated in the eastern part of India is not an exception to this. Besides construction of dams and embankment, man has changed the nature of this river by unscientific overexploitation of riverine sand not only from the river bed but also fertile river bars and adjacent river terrace which leads to environmental disruption through adverse dramatic impacts on the river morphology, ecosystem, hydrology and environment. Though from an economic and flood management point of view, we have to mine this inexpensive resource from river, we should follow scientific methods in appropriate mining sites. For this purpose, study of river sensitivity based on active and total channel area can be a good strategy. In the case of Damodar river, using sensitivity we classified 12 reaches in very low, low, moderate and high sensitive sections and suggested section wise which method should be applied. We hope that this study will help to use rivers in a sustainable way.

Keywords: Damodar river, sand quarrying, river morphology, sensitivity, sustainable sand mining.

SAND has now become one of the most widely consumed natural resource in the world as it meets the need of raw materials for infrastructural development towards global economic growth which was initiated from the second half of the last century[1]. For this raw material, India and other developing countries are dependent mainly on rivers. Sand can be easily extracted from rivers, and compared to other sources, materials in alluvial deposits are of better quality and well sorted by abrasion processes that separate weak and strong materials[1–4]. At present, the huge demand for sand due to rapid urbanization and industrialization is mostly responsible for unscientific, indefensible and illegal extraction of sand not only from the river bed but also from fertile river bars and adjacent river terrace deposits. A study by United Nations Environment Programme[5] estimates that the world consumption of aggregates exceeds 40 billion tonnes per year, which is double the total sediment carried by world rivers in a year[5–7]. Thus, extractions of sand higher than the natural replenishment capacity of a river destroy the balance between deposition and erosion process of a channel and increase the risk of environmental disruption through adverse dramatic impacts on river morphology, ecosystem, hydrology and environment. Some of these impacts are: (a) Upstream and downstream incision[1,2,8–16], (b) Changes in channel morphometry and planform including thalweg relocation[10,12,14,16–26], (c) Changes in the characteristics of sediment and its transport[11,23,26–31], (d) Shifting of pool-riffle sequence and river bank erosion[11,32–34], (e) Instability of river bars[33,35], (f) Lowering of the ground and surface water levels[11,36–39], (g) Water pollution and its effects on aquatic ecosystem[5,40–44]. Apart from these, as mined rivers are erosional in nature, it also affects the agricultural system of the flood plain by eroding agricultural land. During transportation of mined sand, the sand-loaded trucks block the embankment and roads which hampers daily life and create problems to reach the school, market and/or hospital. Also, wet pit mining sites are responsible for loss of life. Water, air and sound pollution are quite common in the mining region which also affects the health of local people. Weak governance, corruption, illegal mining and trading of sand lead to social unrest as these activities are associated with the business of millions of rupees. But, on the other hand, scientific mining can increase the carrying capacity of the river which can help in minimizing the flood risk and can be an effective tool for channel stability in rapidly aggrading rivers[3]. It can also generate employment, can provide better economic conditions to poor labourers, and can increase the income of government or GDP of the country which is vital for infrastructure development. As our modern civilization highly depends on sand, considering the adverse impacts, it is not possible to leave the river in its natural state. We have to mine this inexpensive resource from the river but with scientific methods at appropriate sites so that the river can be used in a more sustainable way.

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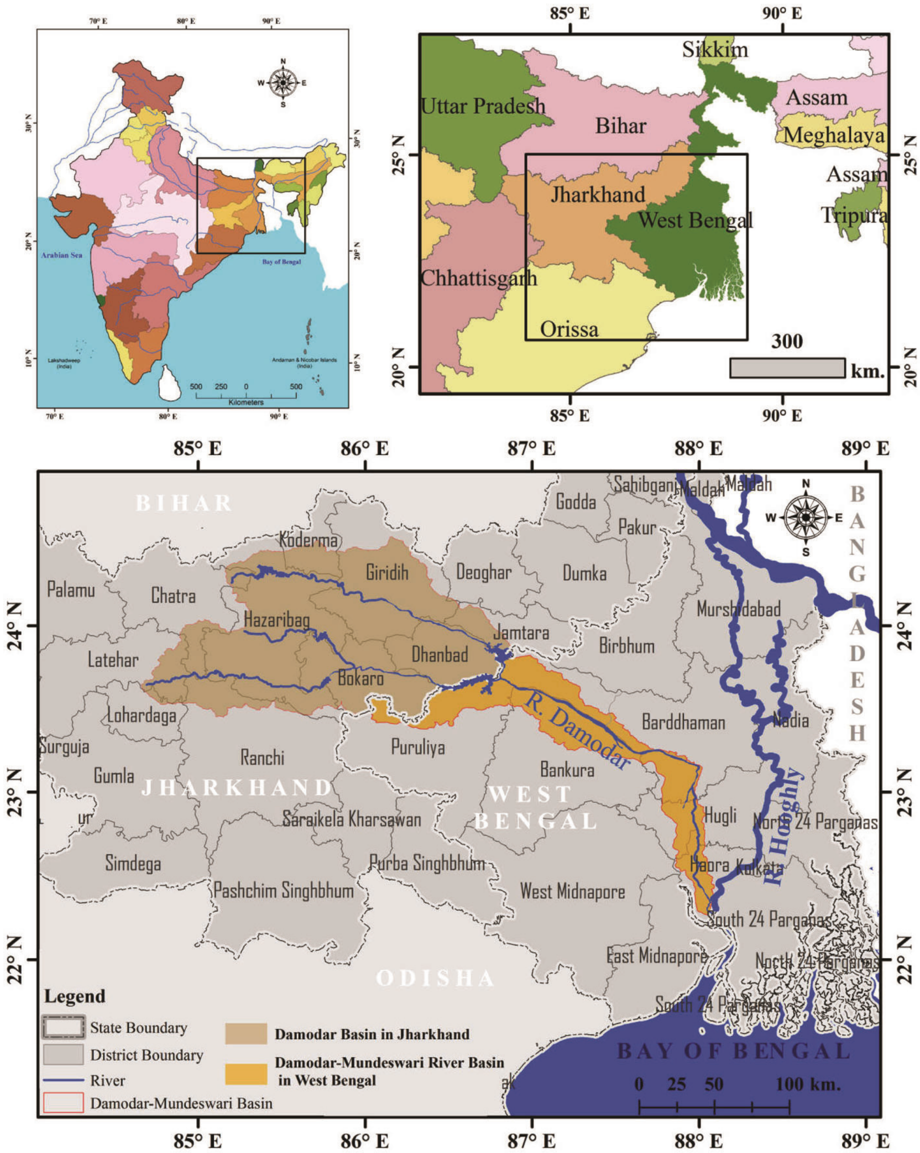

Figure 1. Damodar river basin: its location and divisions.

The objective of this study is to find a suitable method and appropriate reaches for quarrying of sand from Damodar river in West Bengal of Eastern India with help of the concept of 'sensitivity'. River as a system always tries to maintain an equilibrium condition by balancing between the input and output. Any kind of interruption within this system may alter hydraulic variables such as slope, velocity profile, depth, width, stream power of the river and result in changes in its morphology. Instead of a continuous mode, these changes occur through steps known as geomorphic threshold which is highly correlated with geomorphic sensitivity[45,46]. If a part or reach within a river is close to the threshold value, it will be highly sensitive and a small external alteration of input can introduce a significant change in the morphology of that reach[46]. A pioneering work on landscape sensitivity was done by Brunsden and Thornes[47], who described landscape sensitivity concept as a sensible, recognizable and persistent response produced by a system due to changes in the control of that system. According to them, landscape sensitivity depends on two aspects, i.e. the tendency for change and the capacity of the system to absorb the change. Thereafter, many researchers and the scientists[45,46,48–58] have done studies and provided the scientific basis of the concept of sensitivity of a geomorphic system. From these studies, we can simplify that sensitivity is a function of the spatial and temporal distributions of the resisting and disturbing forces. Similarly, river reaches also continuously try to balance between disturbing and resisting forces through changes in their morphology. These changes may occur in lateral, vertical or entire dimension[56].

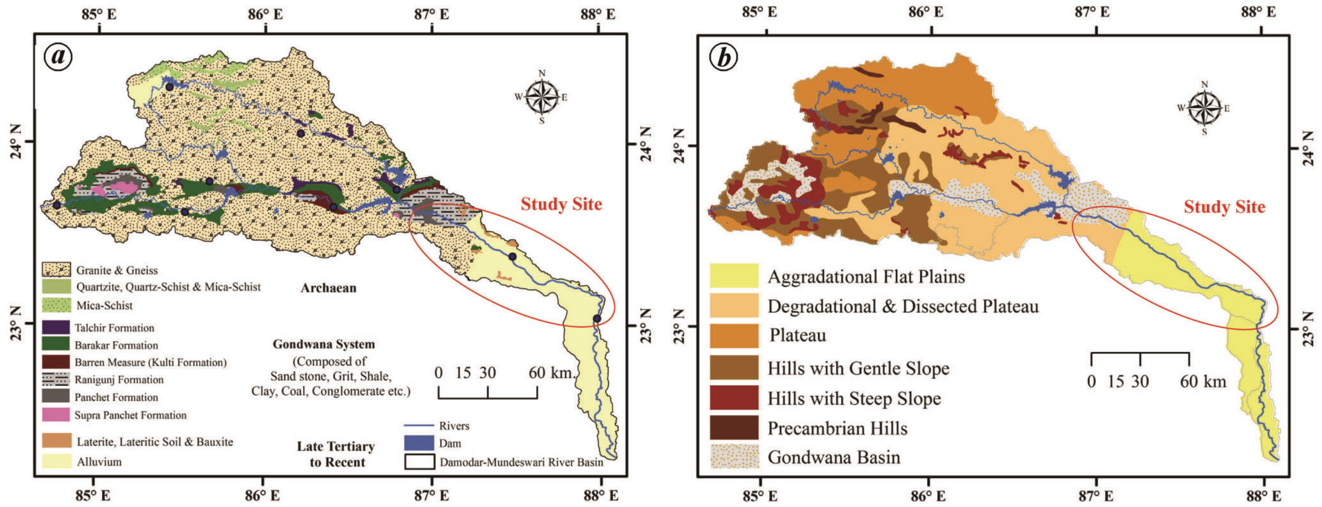

Figure 2. (***a***) Lithology and (***b***) Geomorphological divisions of Damodar-Mundeswari river basin. The figure has been prepared by authors combining different secondary data sources, which are mentioned and referenced in Database and Methodology section.

Study area

Damodar river, one of the most important drainage systems of the Bhagirathi–Hooghly river basin or Lower Ganges Basin in eastern part of India (Figure 1), flows through mineral rich Chotanagpur craton and highly populated Bengal basin area. This river originated from Birjanga hill (23°38′35″N and 84°39′40″E) of Chotanagpur Plateau at an elevation of 1000 m above mean sea level (amsl) drains (total length 577.81 km) over the districts of Jharkhand (295.07 km) and West Bengal (282.74 km) and ultimately meets the Hooghly river at an elevation of 3.8 m amsl (ref. 33). Total area of this tadpole shaped[59,60] basin as demarcated from Survey of India (SOI) topographical maps and shuttle radar topography mission (SRTM) data, is 23,179.78 sq. km spread between 23°38′39.90″N and 84°39′37.01″E to 22°16′35.17″N and 88°04′58.15″E, which can be divided into: (i) Upper portion of Damodar basin in Jharkhand (17,128.69 sq. km) and (ii) Lower portion of Damodar basin in West Bengal (5364.76 sq. km + 686.24sq. km of Mundeswari river basin; Figure 1).

If we consider a lithological map (Figure 2 *a*) of the entire basin, we can observe that the upper portion of the basin is mainly part of the peninsular shield composed of Achaean granite, gneiss with disperse arrangement of Gondwana sandstone, shale, clay, coal and conglomerate (known as Talchir, Barakar, Ranigunj and Panchet Formation)[61–63]. While, lower Damodar basin in West Bengal is the part of Bengal basin filled mainly by Pleistocene to Recent alluvium[61–63]. From morphological point of view, this basin is divided mainly into two parts: (a) Aggradational flat plain situated in lower part of the basin, and (ii) Degradational dissected plateau in upper basin[62] (Figure 2 *b*). Eroding of quartz-rich Archaean gneiss and sandstone-rich Gondwana sedimentary in its upper and middle plateau region, and deposition of these eroded materials in the lower course makes the Lower Damodar river (below Durgapur) rich in good quality sand[33].

We have selected the lower portion of the basin in West Bengal (Figure 2 *a* and *b*) for our study because, this aggradational flat plain covered by alluvium is a rich source of sand and thus highly affected by indiscriminate sand mining. Besides, alluvial rivers are more sensitive systems which show and hold detailed sign of rivers' response to environmental and human induced changes over a wide range of temporal and spatial scales[64].

Data base and methodology

Damodar river basin demarcated from SRTM data and 59 numbers of SOI topographical maps, whereas administrative boundaries are marked based on the database of global administration areas (v. 2.5), July 2015. Lithological and geomorphological maps were developed using data sources of Chatterjee[62], Sen[65] and geological quadrangle maps of Geological Survey of India (GSI map no. 73I, 73J, 73M, 79A and 79B). For better analysis, we divided the lower part of Damodar river within West Bengal into 19 different reaches (Figure 3) based on channel characteristics, keeping in backdrop the Rosgen's method of channel classification[66]. We took only first 12 reaches for our detailed study, because, after this (below Jamalpur), the effect of river control by embankment was so huge that in this portion, morphologically River Damodar was unable to shift laterally in the last 100 years.

As it is difficult to find out the 'threshold boundary' for geomorphic change in reaction to external forces, and as different reaches of a river respond differently for the same forcing mechanism, the concept of sensitivity is important[46]. In a normal condition, with the same type and magnitude of disturbing forces, compared to a lower one, a highly sensitive reach will respond more significantly by altering its planform. Therefore, identification and quantification of changes in morphology can indicate or act as proxy of river sensitivity. Hence, to study the sensitivity, we tried to find out the reach-wise changes of planform of Damodar river over the last 100 years. Vector data of river bank in different years were used in Digital Shore Line Analysis System (DSAS)[67] to statistically compute the rate of change for all the mining and non-mining sites. In DSAS platform, transects were plotted considering the middle of the river as baseline. Shoreline change envelope (SCE) was computed to represent the total shifting of the riverbank, end point rate (EPR) to calculate year-wise changes and linear regression rate (LRR) for the distance of all shoreline points along a particular transect from the least-squares regression line. Along with these, some field survey techniques were also applied for better understanding of sensitivity. To measure the changing pattern of channel morphology, we have used the concept of braid-channel ratio and sinuosity index after Friend and Sinha[68]. Downs and Gregory[51] described sensitivity as a ratio between the magnitude of channel adjustment and the magnitude of change in the stimulus causing adjustment. Reid and Brierley[69] measured reach-wise river sensitivity based on the changes of active and total channel area and valley length. Here we have used the ratio of active and total channel area to quantify the sensitivity of different reaches. To find

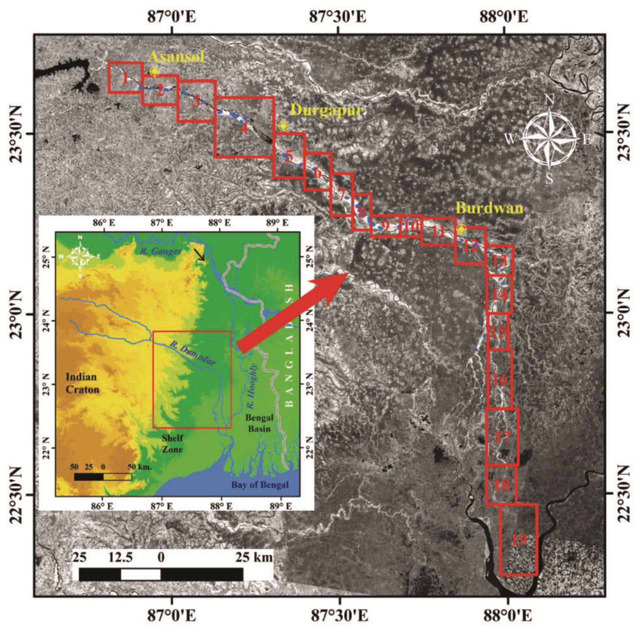

Figure 3. Classification of lower section of Damodar river into different reaches. Points within the river indicates the location of legal mining sites.

out the active and total channel area for nearly the last 100 years, we used different topographical maps of SOI such as 73I/14, 73M/7, 73M/11(RF 1 : 63,360) and 73M/NW, 73M/SE, 73M/SW, 73MN/NE (RF 1 : 126,720) surveyed during 1929, and 73I/13, 73I/14, 73I/15, 73M/1, 73M/2, 73M/3, 73M/4, 73M/6, 73M/7, 73M/8, 73M/11, 73M/12, 73M/15, 73M/16 (RF 1 : 50,000) surveyed mainly during 1972. Corona declassified type-1 satellite image (Entity ID: DS1021–2134DF040, DS1021–2134DF042, DS1021–2134DF043, DS1021–2134DF044 of 27 May 1965 and DS1038–2102DA178, DS1038–2102DF180 acquisition on 21 January 1967), Corona declassified type-2 satellite image (Entity ID: DZB1216–500514L004001 acquisition on 10 October 1980). Landsat TM satellite image (Entity ID: MTN-45-20_LOC) acquisition between 8 February 1988 and 1 November 1992, Landsat 7 ETM + (Entity ID: EPP139R044_7F20011026, Path 139 and Row 44) of 26 October 2001 and Aster L1T data (Entity ID: AST_L1T_00312172014045443_20150624201530_11844 and AST_L1T_00311242014044838_20150624071904_74204) of 27 December 2014 and 24 November 2014 which are geo-coded with Universal Transverse Mercator projection, spheroid and datum WGS-84, Zone North 45. All these maps and satellite data were digitized in Arc-GIS v-10.2 platform and calculated to get reach-wise active and total channel area for sensitivity study of Damodar river. Then the year-wise ratio of active and total channel area and their average values were calculated. The value 1 indicates that active and total channel area is same; its mean river had not migrated in the last 100 years. For better understanding we subtracted the average value from 1. Thus, reaches with the subtracted value near ‘1’ were considered sensitive as they responded frequently, while those near ‘0’ indicated low sensitivity as their responses were negligible and infrequent. Low sensitive reaches are those which have less than mean sensitive value while highly sensitive reach has more than [mean + SD of {1 – average (active: total channel area)}] sensitive value.

Results

Like majority of other states of India, nearly all rivers of West Bengal are highly affected by indiscriminate sand mining. Rivers in West Bengal, that are especially from the mineral rich Chotanagpur plateau, are well known for good quality sand and hence extreme interference by human activity. In its upper and middle courses, Damodar river flows through a large area in Jharkhand and erodes the quartz-rich Achaean granite, gneiss and sandstone-rich Gondwana sediment. The deposition of these eroded materials in the lower course of Damodar (below Durgapur) helps to share a big percentage of the mined sand in West Bengal. At present the number of legal mining sites in the 145 km stretch of Damodar river between Saltore and Jamalpur (i.e. Reach 1 to 12 in Bankura, East and

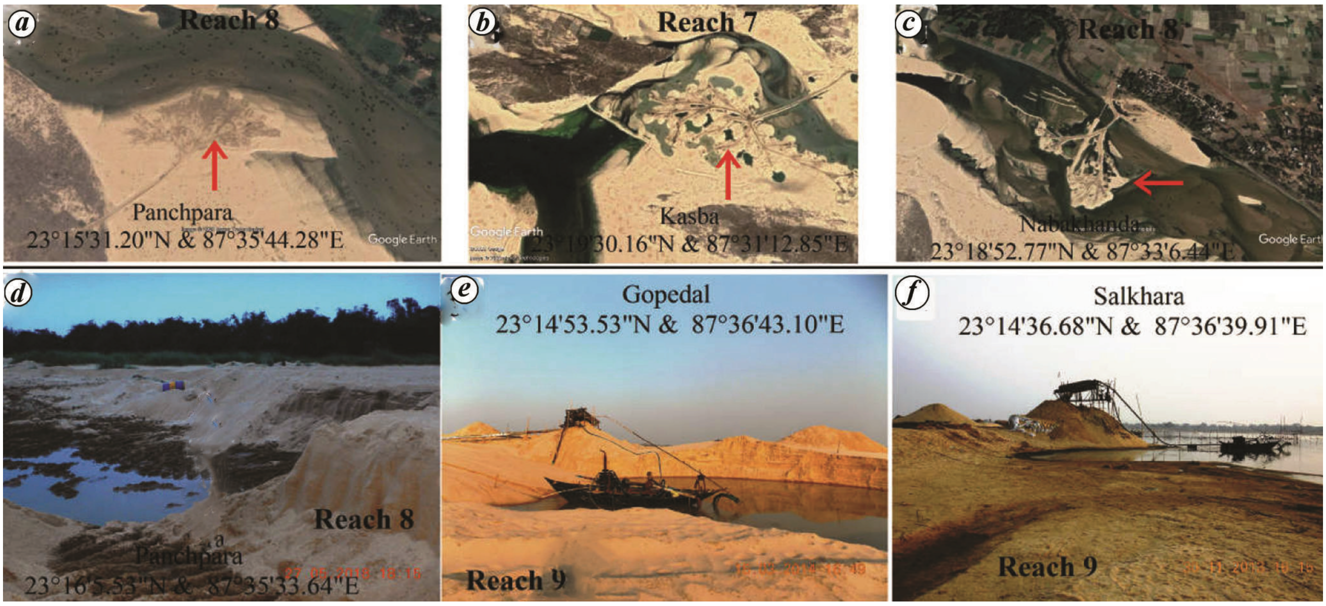

Figure 4. Methods of sand mining ***a***, ***b*** and ***c*** represent aerial views (Google Earth Image), while ***d***, ***e*** and ***f*** represents field photographs of different mining sites: (***a*** and ***d***) Bar skimming; (***b*** and ***e***) Dry pit mining and (***c*** and ***f***) Wet pit Mining.

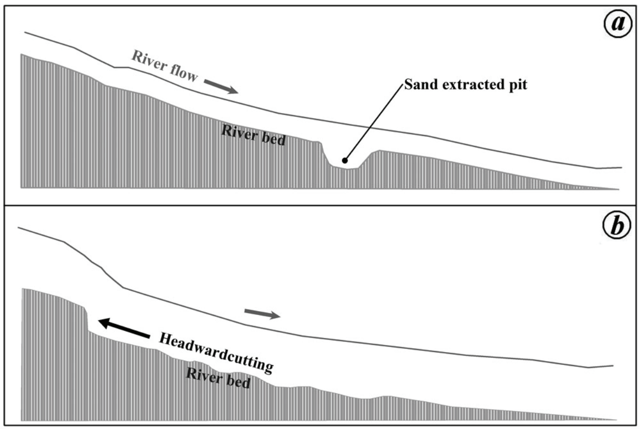

Figure 5. Graphical representation of river bed incision due to wet pit mining from river bed.

West Barddhaman districts) is 135. While permission has been given by the Government of West Bengal to extract 12,241,058 m^3 volume of sand, the amount of extracted sand is far more than this due to illegal mining sites.

In this area, sand is mainly mined by three methods. (i) Bar skimming which involves scraping of the top layer and its impact on the river is less (Figure 4 *a* and *d*); (ii) Dry pit mining or mining from dry ephemeral streambeds whose adverse effects on the river is more than bar skimming (Figure 4 *b* and *e*); and (iii) Wet pit mining which indicates extraction below the water table level or from a perennial stream and has dramatic environmental impacts (Figure 4 *c* and *f*).

During wet pit mining, huge amounts of sand are extracted from a point within the perennial part of the stream. By generating turbulence, these mining induced pools play a significant role in head-ward erosion[11] that tends to move for kilometres upstream and changes the river morphology (Figure 5). A similar result can be observed in Damodar river near Konarpur (Reach 11) in West Bengal; where, on a concrete pillar, we marked the scale in the year 2014. After 3 years, we observed that the river bed level incised up to 3.75 m (Figure 6), and this may be due to severe extraction of sand from wetted part 700 m below the pillar site. Besides river bed incision to measure the channel pattern, we calculated reach and year-wise sinuosity index, braiding index and braid–channel ratio and plotted those values after Friend and Sinha's[68] useful method of measuring the variable channel morphology for different types of Indian rivers (Figure 7). According to their study, the values of braid–channel ratio and sinuosity index '1' indicate straight course of a river; similarly elongated shape of plotted points indicate the braided pattern, and tall shape indicates meandering pattern. In this case, continuous decrease of braid–channel ratio as well as elongated shape signifies that besides river bed incision, the channel pattern of Damodar river swings from braided to straight or multi channel (Figure 7). Several cross sections of the river (Figure 8) in mining Reaches also indicate that it becomes straight, narrow and incised with time. This changing channel pattern leads to erode its bank in some places and construct in others. Statistically, to quantify the amount of river bank erosion or accretion for all the Reaches, we computed LRR, EPR and SCE using DSAS with the help of different satellite images available after 1965. The results showed that the negative LRR values could be observed in Reach 5 and 11 along left bank, and Reach 7 and 8 along right bank, while positive values were observed in

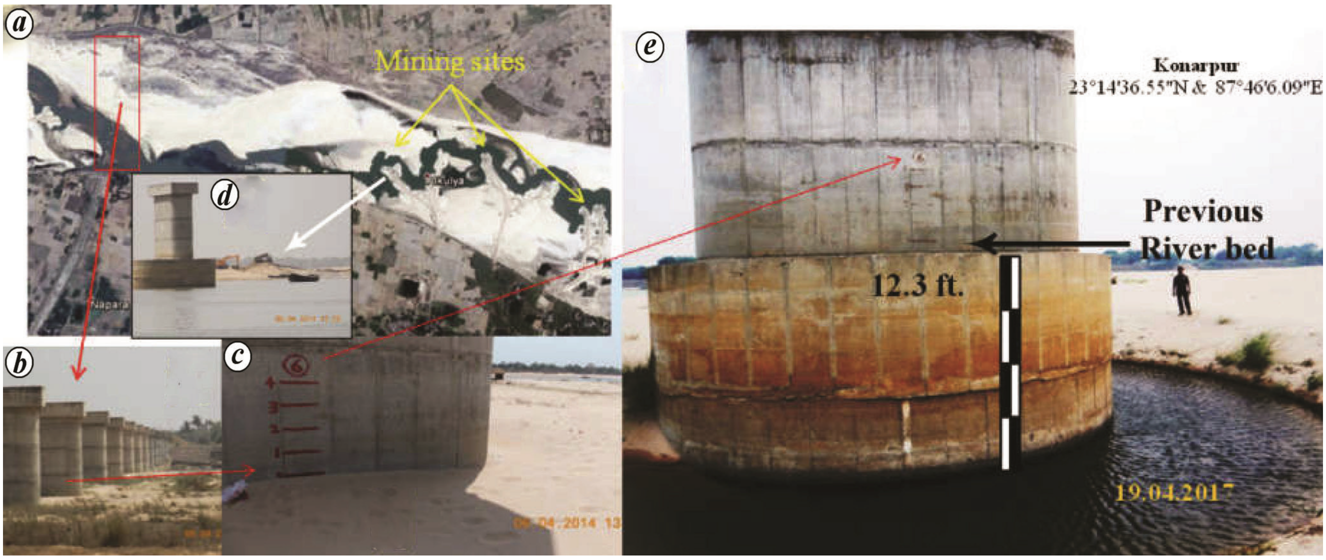

Figure 6. River bed incision due to sand mining in Reach 11. ***a***, Google Earth Image indicating the location of concrete pillars and sand mining sites. ***b***, Photograph of the same pillars. ***c***, scale (in ft.) drawn in the base of the pillar ('0' indicate the river bed in 2014). ***d***, Sand extracted from the river bed just below the pillars and ***e***, Photograph of same pillar in 2017 representing river bed incised about 12.3 ft. in this site.

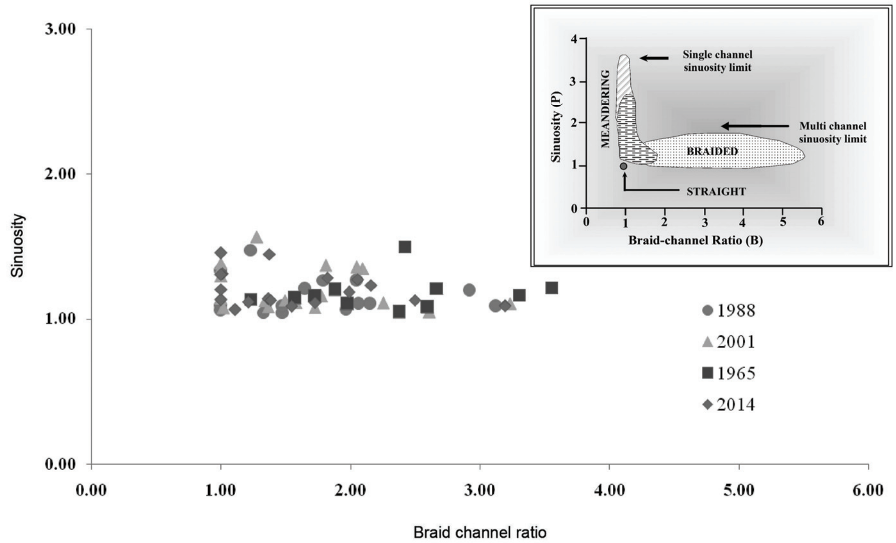

Figure 7. Reach-wise plotting of sinuosity and braid-channel ratio after Friend and Sinha's method[33] to measure the channel pattern of Damodar river.

Reach 7, 8, 9 and 12 along left bank, and Reach 10 and 11 along the right bank of the river (Figure 9 *a*). Negative EPR values, i.e. more than 20 m/year depositional rate was observed in Reach 5, 7 and 11. On the other hand, maximum reaches below Reach 5 along left bank were erosion prone with more than 0 to 25 m/year EPR value (Figure 9 *b*). EPR and SCE values were of similar types; first one indicated year-wise shifting and second one pointed out total shifting of river bank in the studied period. Since identification and quantification of changes in morphology are able to indicate or act as proxy of river sensitivity, SCE values would be helpful in this case. None or less than 10 m shifting of river bank in the last 50 years has occurred in Reach 1 to 4, whereas more than 500 m shifting of either left or right or of both banks could be observed in some places of maximum reaches in between 5 and 12 (Figure 9 *c*), which represents higher sensitivity of the lower segment compared to the first four reaches.

We measured geomorphic sensitivity of Damodar river based on reach-wise lateral channel response measured from satellite images and old maps. After the digitization of old maps and satellite images, we calculated reach-wise 'active channel area' (Figure 10) and 'total channel

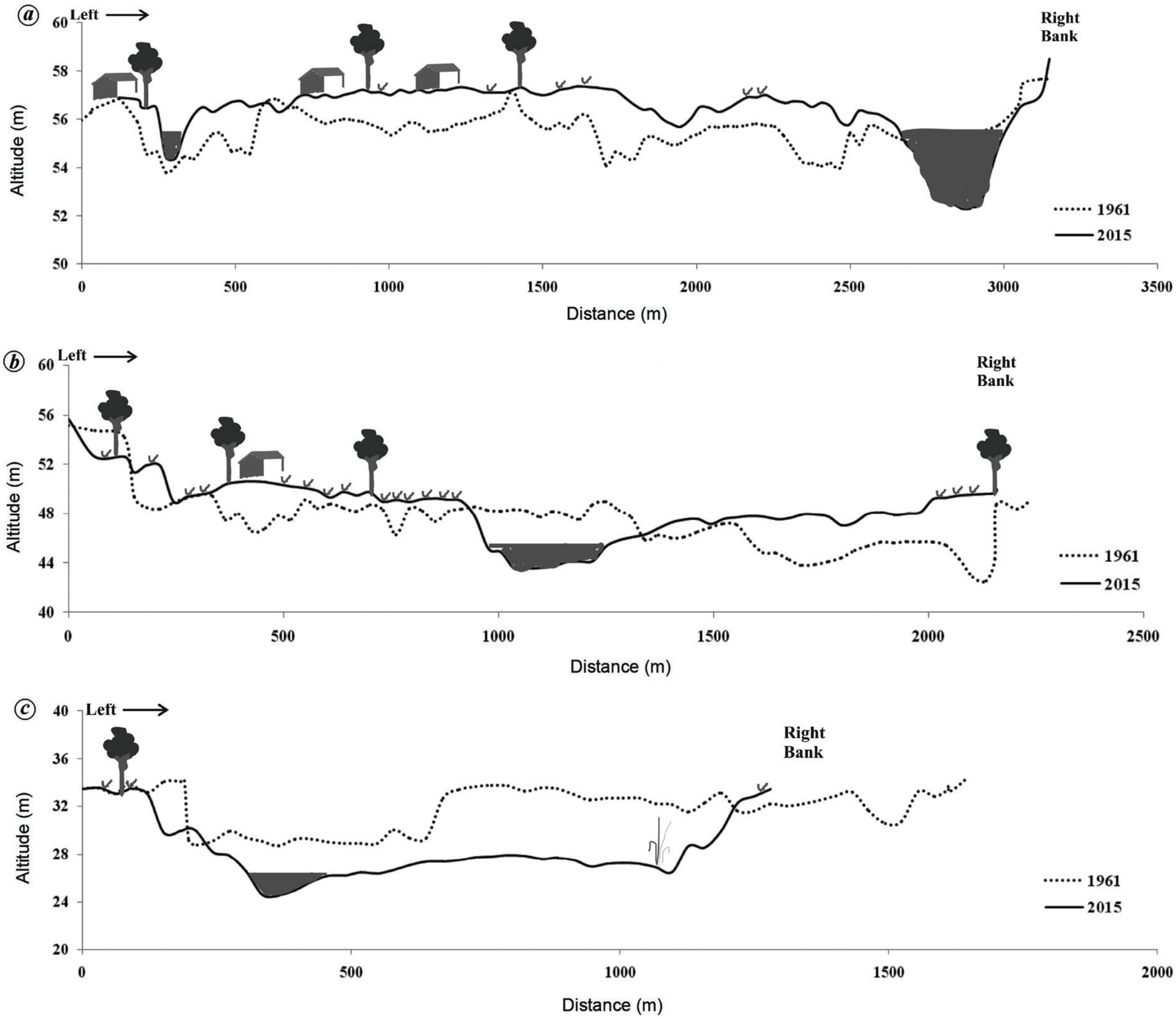

Figure 8. Cross-section of Damodar river at (***a***) Reach 5 (10 km downstream of Durgapur barrage near Pakhanna), (***b***) Reach 7 (3 km downstream of Randiha), (***c***) Reach 11 (4 km upstream of Barddhaman Sadarghat bridge near Idilpur). Data source: Damodar Valley Corporation and field survey.

area' (Figure 11) for individual year. The 'active channel area' in this study represents the area of channel being actively modified by average stream discharges, and 'total channel area' indicates the area (along with active channel area) over which the river migrated in the last 100 years.

Based on reach and year-wise ratio of active and total channel area, sensitivity of River Damodar is calculated and presented in Table 1. A value near '1' is considered sensitive as those reaches respond frequently, while near '0' indicates low sensitive as responses are negligible and infrequent. From the result of this study we found higher sensitive values of lower reaches below Durgapur.

Discussion

Different adverse impacts of sand quarrying activities on River Damodar as identified by Ghosh *et al.*[33] are: (i) Shifting of river thalweg and instability of river bars, (ii) Channel planform changes, (iii) Shifting of pool–riffle sequence and river bank erosion, (iv) Variation in channel width, and (v) Riverbed degradation. However, as stated earlier it has also some favourable effects in terms of economy, flood risk control and channel stability. At this present juncture, to use the river in a sustainable way, besides strong governance we have to identify scientific methods and appropriate sites of sand mining based on 'river sensitivity'.

LRR, EPR and SCE values in DSAS (Figure 9) indicate that the width of the river in between Reach 1 and 4 remains almost same, while maximum changes of planform occurred below Durgapur between Reach 5 and 12. This is because, from a lithological point of view (Figure 2), these reaches were flowing through more sensitive alluvium flood plain. Compared to right, the left bank of the river is more affected by uncontrolled volumes of sand

Table 1. Reach-wise calculation of Sensitivity of Damodar river

Reach	Active: Total channel area							Average	1-Average
	1929	1965	1972	1980	1990	2001	2014		
1	0.9782	0.9815	0.9829	0.9824	0.9946	0.9948	0.9708	0.9836	0.0164
2	0.9343	0.9184	0.9142	0.9476	0.9519	0.9639	0.8819	0.9303	0.0697
3	0.9777	0.9759	1	1	0.9849	0.9687	0.9642	0.9816	0.0184
4	0.7799	0.8015	0.8305	0.8134	0.8115	0.7435	0.6174	0.7711	0.2289
5	0.7375	0.6481	0.6124	0.7237	0.632	0.5763	0.8037	0.6762	0.3238
6	0.45	0.6719	0.8276	0.7801	0.8164	0.7654	0.7359	0.721	0.279
7	0.311	0.364	0.5996	0.8427	0.8507	0.8008	0.9307	0.6714	0.3286
8	0.3899	0.4744	0.8755	0.9505	0.9391	0.8843	0.6739	0.7411	0.2589
9	0.4736	0.5985	0.808	0.8128	0.8279	0.8265	0.7245	0.7246	0.2754
10	0.6636	0.8315	0.8953	0.8475	0.8473	0.8158	0.9097	0.8301	0.1699
11	0.6166	0.5448	0.4913	0.6357	0.5705	0.775	0.942	0.6537	0.3463
12	0.6995	0.76	0.7889	0.8864	0.8694	0.8778	0.7965	0.8112	0.1888
				Mean					0.2087
			Standard deviation (SD)						0.113

Numbers in red colour indicate highly sensitive, pink colour represent moderately sensitive, light green and deep green colour specify low and very low sensitive values respectively.

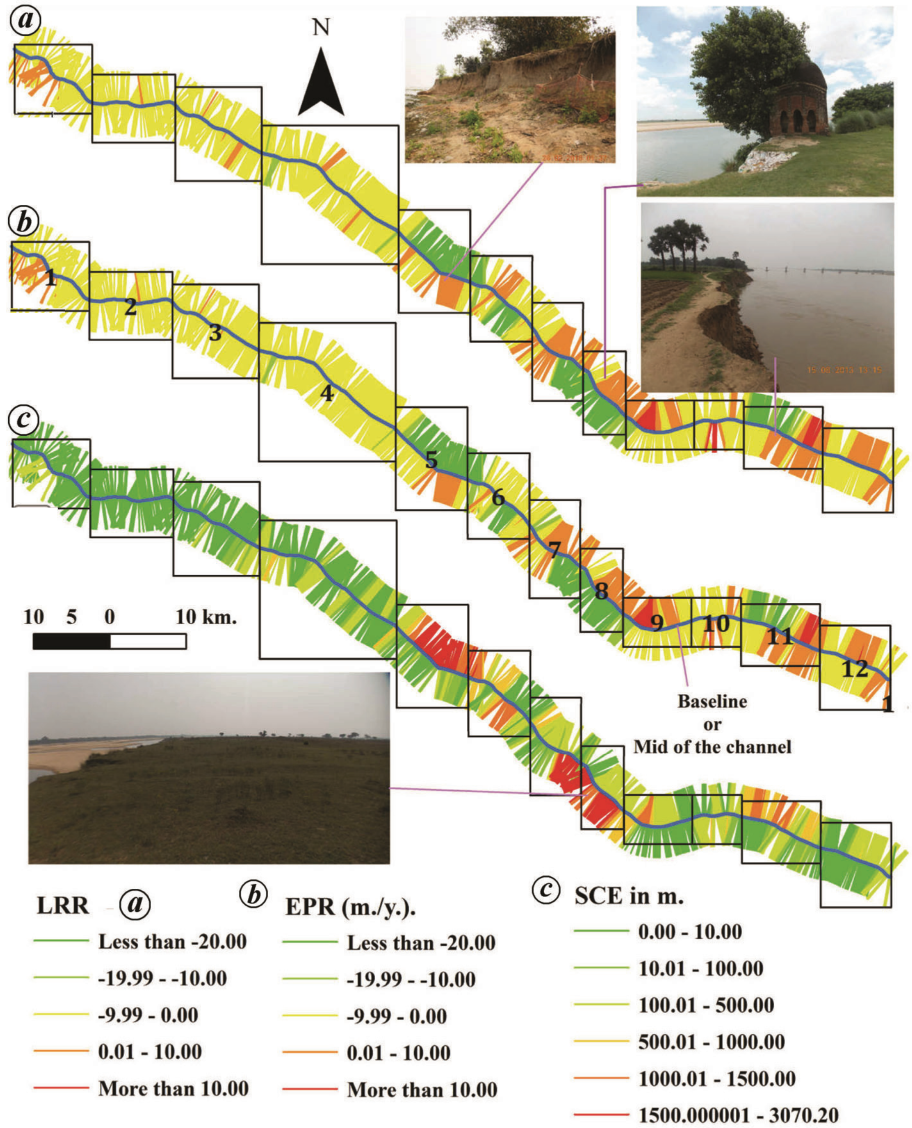

Figure 9. Reach-wise river bank accretion and erosion of Damodar river in West Bengal.

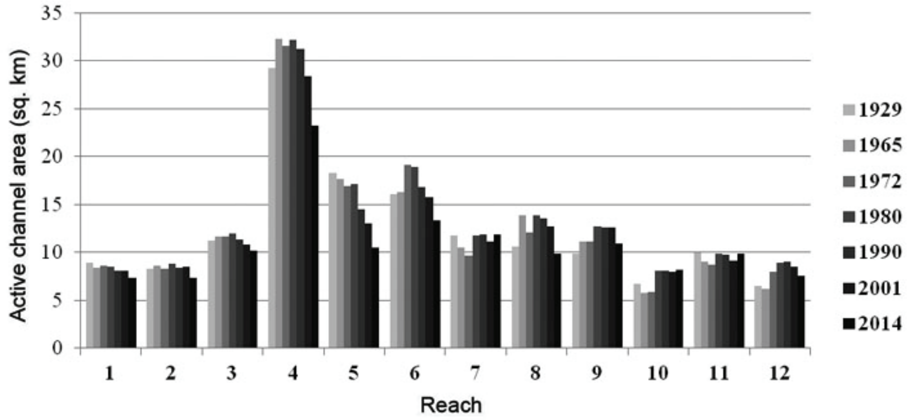

Figure 10. Reach-wise changes of active channel area of Damodar river between 1929 and 2014.

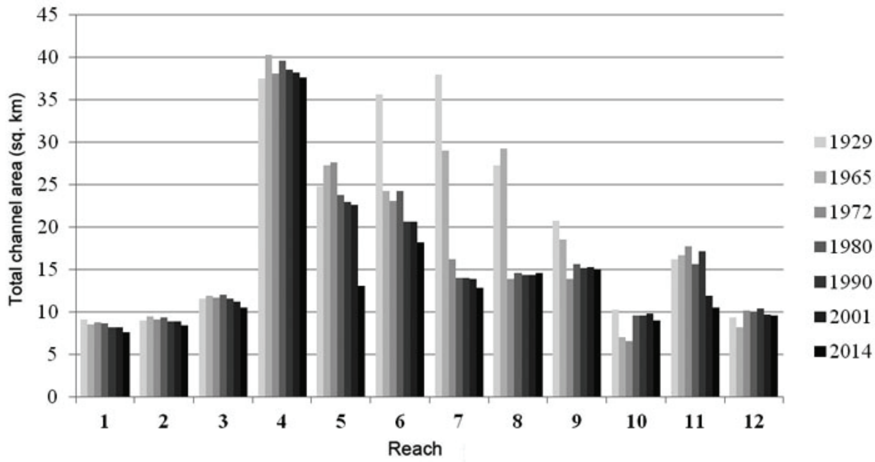

Figure 11. Reach-wise changes of total channel area of Damodar river between 1929 and 2014.

extraction because of its accessibility due to the presence of a national highway (NH-2) nearby. This may make left bank more erosion prone except Reach 5 and 11 as indicated by EPR values (Figure 9 *b*). Existence of two big cities 'Durgapur' and 'Burdwan/Barddhaman' in the left bank of Reach 5 and 11 (Figure 3) may create a barrier in illegal mining, and helps the river bars along the left bank in these two reaches to remain stable. On the other hand, lack of transport facilities due to the presence of 'sali' river, helps in protecting the right bank from indiscriminate sand mining as well as from erosion up to Reach 9 and after that the right bank of the river is also erosion prone. As indicated by SCE values, more than 500 m shifting of river bank can be observed in maximum reaches between 5 and 12 (Figure 9 *c*) after the year 1965. In this case the construction of many dams and barrages in Damodar river basin (between 1950 and 1960) played a significant role because the average discharge of Damodar river at Randiha (Reach 7) reduced from 4162 m^3/s to 2737 m^3/s during post-dam period[60]. This type of major perturbation linked with monsoonal hydrodynamic behaviour as well as uncontrolled and unscientific sand mining interrupt the river to achieve a balanced condition which affects the whole system and the highly sensitive reaches respond more comprehensively by altering its planform. To find such sensitive reaches and their scale, we have used the concept of 'active and total channel area' of River Damodar for the last 100 years. From this study, we identified Reach 5, 7, 11 as highly sensitive reaches (H) because, the sensitivity value of these reaches were more than 'mean + SD' value of '1 – average of active and total channel ratio' sensitive value. This indicates that these reaches use more area for their lateral movement or shifting. Reach 4, 6, 8 and 9 are moderately sensitive (M). Reach 10 and 12 are identified as low sensitive (L), while Reach 1, 2 and 3 became very low sensitive (VL) as, in these reaches the active and total channel areas were almost the same and had a sensitivity value less than the mean sensitive value which points out that River Damodar has not migrated in these reaches from 1929 to 2014. Thus, overall sensitivity for each reach was obtained with reach scale sensitivity ranks based on sensitivity values such as H1 representing highly sensitive with first rank. Planform adjustment map (Figure 12) thus indicates that Reach 11, 7 and 5 are highly sensitive reaches holding first to third rank respectively, because,

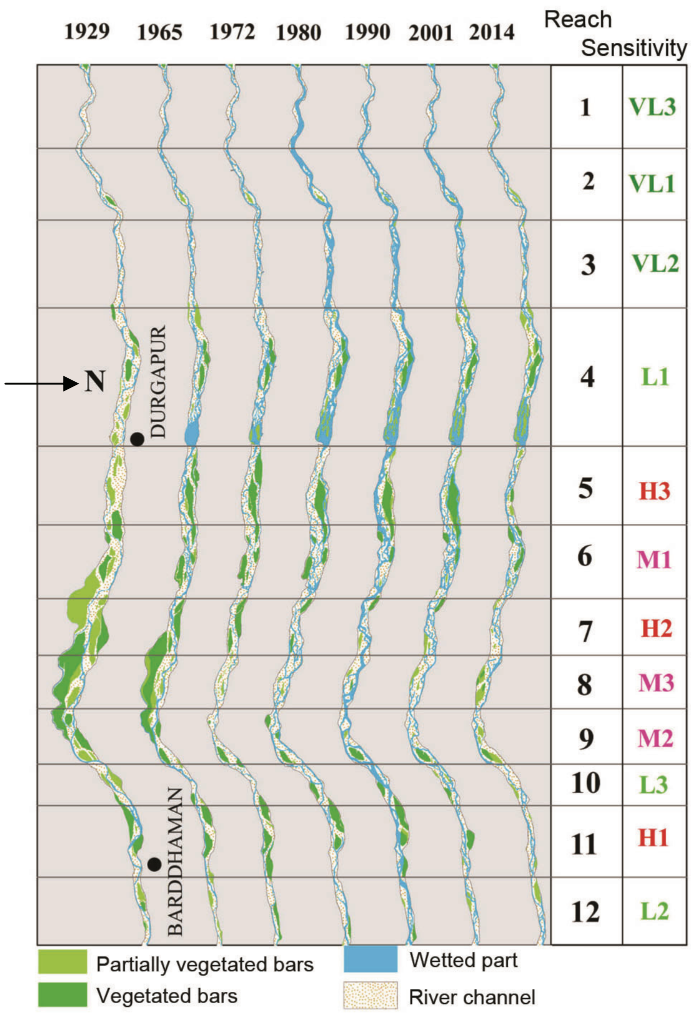

Figure 12. Planform adjustment along the reaches of Damodar river from 1929 to 2014 with their sensitivity rank.

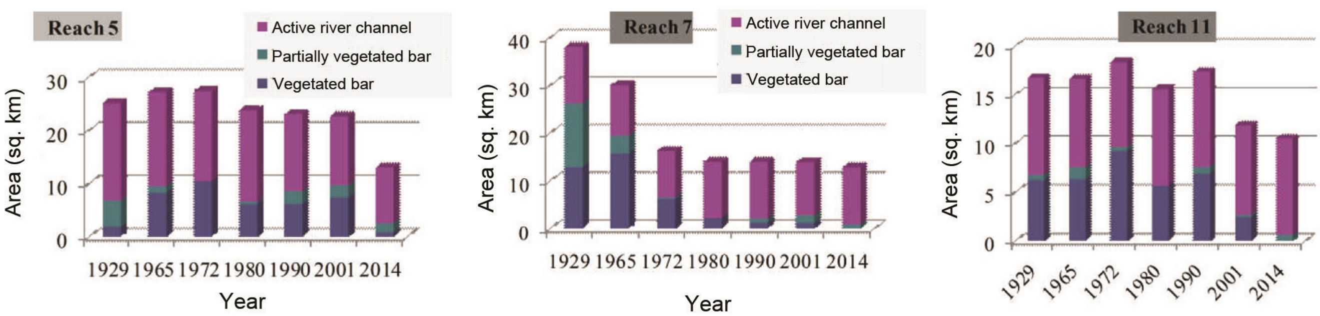

Figure 13. Vegetated, partially vegetated and un-vegetated or active channel areas for the highly sensitive reaches over time.

in these reaches River Damodar had shifted its course many times by forming numerous bars which after some years joined with the main land. As a result, total channel area of these reaches has increased with time, but active channel area remains almost the same (Figure 13) which, at the same time increases the difference between active and total channel area. As the Reach 5, 7 and 11 of Damodar river, are highly sensitive, mining should not permitted in these reaches. Bar skimming and dry pit mining should be permitted in Reach 6, 8, 9 and 10, 12 respectively. As the Reach 1, 2 and 3 have low sensitivity, wet pit mining may be permitted along these reaches (Figure 14 and Table 2). Obviously, there should be some restrictions regarding the amount and depth of extraction; the

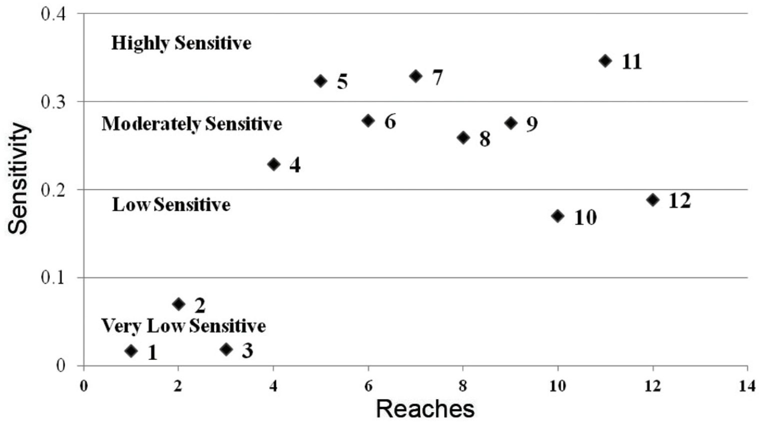

Figure 14. Sensitivity of different reaches of Damodar river.

Figure 15. Local people's perception about sensitivity.

Table 2. Reach-wise permissible mining types from the river bed of Damodar

Sensitivity	Reach	Allowable mining types	Impacts on river
High	5, 7, 11	No mining	Low
↑	6, 8, 9	Bar skimming	↓
	10, 12	Dry pit mining	
Low	1, 2, 3	Wet pit mining	High

reaches also must be given some time to regain their capacity. Although we have measured the sensitivity of Damodar River based on different old maps, satellite images and calculations, the provided picture (Figure 15) shows the in-depth knowledge and experience of local people about sensitivity. They know better where the new bar will be formed. Accordingly they would readily construct borders and plant trees to capture the newly formed land which will be developed in the currently active channel area. Therefore, the knowledge and experience of riverside dwellers should be incorporated in planning.

Conclusion

In the present age of industrialization and urbanization, the demand of sand is ever increasing. Developing countries like India use rivers to fulfill this demand as the methods of superior quality riverine sand extraction is quite simple and cost effective. As these activities are associated with the business of millions of rupees, dishonesty, weak governance and corruption cause violation of the mining guidelines. This unscientific, indefensible and illegal extraction of sand from the river bed, bars and flood plain has dramatic adverse effects on river morphology, ecosystem, hydrology and environment. However, considering the economic and flood management point of view, we have to mine this inexpensive resource from river, but should follow scientific methods in appropriate sites. In such a case, study of the river sensitivity can be a good strategy as shown in the case of Damodar river in India. During Anthropocene, when almost all rivers are at the edge of threat, we have to use them in sustainable ways to save the rivers and their environment.

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