Research Journal of Environmental and Earth Sciences 6(2): 96-101, 2014
DOI:10.19026/rjees.6.5747
ISSN: 2041-0484; e-ISSN: 2041-0492

Submitted: November 04, 2013 Accepted: November 13, 2013 Published: February 20, 2014

Research Article

Morphologic Response of a Stream Channel to Extensive Sand Mining

Aliyu Baba Nabegu
Department of Geography, Kano University of Science and Technology, Wudil

Abstract: This study assesses the impact of sand mining on the morphology of Kano River channel. The river channel was divided into three sites consisting of site upstream of active mining site, active mining site and downstream of active mining. The upstream site was assumed to be unaffected by the mining activity. The mining site was an area of current active mining. The downstream area is downstream of mining site but with no mining activity. A morphometric assessment of 50 sample points in each of the three sites from a cross section was made where width of the channel was measured from one end of the channel to the other horizontally on transect; depth was measured from the lowest point in the flood plain to the top of the bank; channel slope was determined following standard survey technique from points located from the top of one riffle to the top of another within the entire cross section. One-way ANOVA between groups was employed to test the differences between the measured mophometric variables in the three sites. The results revealed that mining activities has resulted in modification of the channel with great variations in depth between the sites ($p<0.01$) with the mining site having 7.5 m the upstream site 2.3 m and downstream 2.5 m deeper than the average channel depth; width also vary between the sites ($p<0.01$); mining site has a mean width of 110 m, downstream site, 75 m and 50 m in the upstream site. Field observation indicate that downstream pools are longer but upstream pools are deeper, expected spacing of riffles given as five to seven stream widths was not observed but riffle interval was however as expected in the mining site.

Keywords: Channel width, channel depth, channel incision, river channel, riffle length

INTRODUCTION

A considerable number of studies have shown that human activities such as sand mining within river channels have greatly accelerated natural geomorphologic processes with negative consequences which includes modification to channel morphology; ground water table lowering, stream-bank instability; flood flow increase and several other biological impacts (Leopold *et al*., 1964; Lagasse *et al*., 1980; Chang, 1987; Kondolf, 1997, 1994; Desprez, 2000; Rinaldi *et al*., 2005; Rovira *et al*., 2005; Chen and Lui, 2009; Nabegu, 2012). The observed impacts have led to numerous studies in Europe, Asia and United states, using a variety of methods and techniques such as by experiments exemplified by the work of Lee and Chen (1996) and Neyshabouri *et al*. (2002), field observations by Neyshabouri *et al*. (2002) and Rinaldi *et al*. (2005), analytical models by Cotton and Ottozawa-Chatupron (1990) and since the late 1980s, by the use of sophisticated numerical modelling by Cao and Pender(2004) and Chen and Liu (2009).

Very few of such studies have been undertaken in Africa and in Kano Region in particular where, the main source of sand is from river bed mining and demand has continued to increase as a result of its utilization as cheap material for housing and infrastructure construction which has been exacerbated by high population growth estimated at 3% per anum and unprecedented urban growth of 40% per anum (Nabegu, 2012). Although, dry pit mining on the surface of the land without reaching the water table is also done in the region, river sand is more desirable because weak materials are eliminated by abrasion and attrition leaving durable, rounded and well-sorted materials that require less processing (Barksdale, 1991). Also, as the economics of sand mining require closeness to the market because of the high cost of transportation, proximity of Kano River to Kano metropolis and the good transport network makes the area attractive to sand mining. However, the inherent complexity of channel evolution makes the extrapolation of results obtained elsewhere unrealistic. This is particularly so considering the fact that present understanding of alluvial channel systems like the Kano River is generally not sufficient to enable the prediction of channel responses quantitatively and with confidence (Lu *et al*., 2007). It is on account of this that this study evaluates the impact of sand mining on the river Kano channel morphology.

MATERIALS AND METHODS

This study was conducted between November 2011 and May 2012. Kano River at Wudil was surveyed to ascertain the number and location of active sand mining

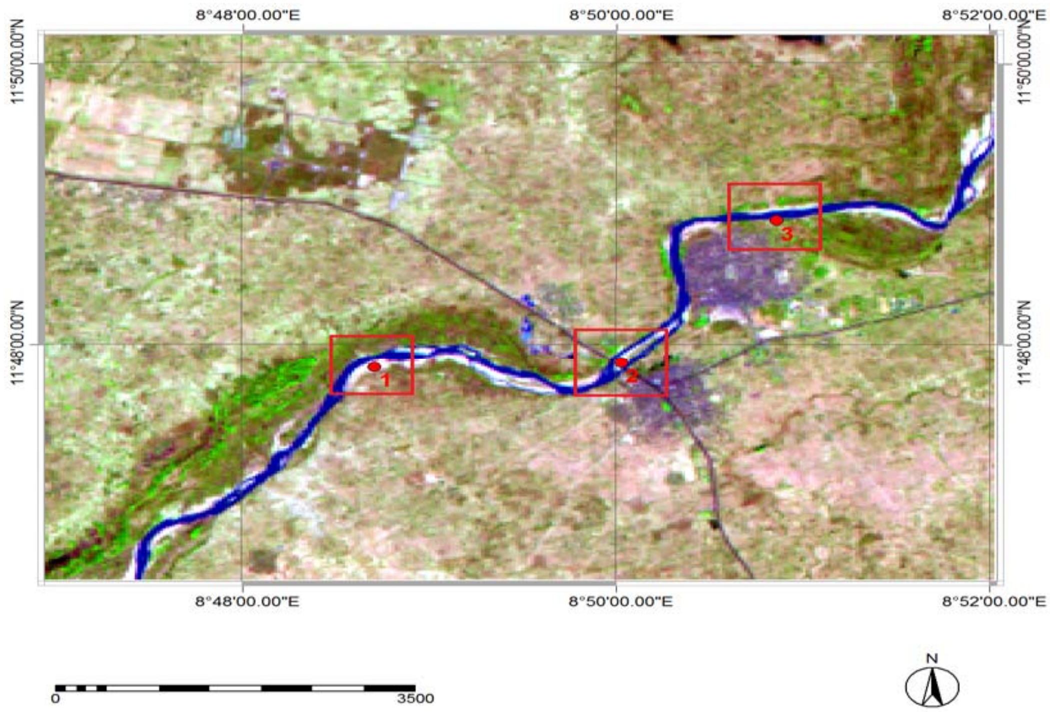

Fig. 1: Kano River at Wudil showing the three sites investigated

points. The focus of the study is on the comparison of the mining site and sites upstream and downstream, consequent upon this, the channel was divided into three sites based on the method used by Brown *et al*. (1998) consisting of:

- Upstream of the active mining
- Active mining area
- Downstream of active mining area

The sites are shown in Fig. 1.

The area upstream of the mining site was assumed to be undisturbed and was thus considered as reference site. The mining site is an area of current active sand mining. The downstream area is the downstream of the active mining site, but with no mining activity. Fifty sample points were selected in each of the three sites for morphometric assessment from a cross section on a transect perpendicular to the main axis of each of the three selected sites. Width of the channel was measured with the use of metal tape from one end of the channel to the other horizontally on transect at 5-m intervals. The depth of the channel was measured from the lowest point in the flood plain to the top of the bank with a steel metal tape at 1-m interval. Channel slope was determined by the use of Abney level to measure the gradient following standard survey technique from points located at the top of one riffle to the top of another within the entire cross section. The ripple pools sequence and spacing was measured after physical observations of the three sites. Data was analyzed for Analysis of Variance (ANOVA).

Study area: Kano River is part of the complex system of the Kamodugu-Yobe basin consisting Hadejia river basin in which three principal tributaries of Kano, Challawa and Watari streams join above Wudil to form what it referred to as the Upper Hadejia shown in Fig. 2. The climate of the study area is the tropical wet-and-dry type which is characterized by a wet season that lasts between 4 and 5 months during where 1100 mm at the watershed to 600 mm downstream of rainfall occurs. The streams are seasonal and have flash flows with flow rising and falling in response to rainfall occurrences. Stream flow is mainly made of quick flow component due to the higher response of the catchment to rainfall input from the expanded runoff contributing area. A programmer of dam construction was perused in the 1970s and there are 25 surface reservoirs today which have modified the stream flow regime. There is flow in the channels during the dry season generated not from rainfall but from reservoir releases. There is also less flooding downstream of the reservoir because the flow or release is regulated.

Downstream of Wudil, the basin is underlain by the Chad basin formation. Upstream, it is underlain by the Basement Complex of Precambrian rocks consisting of older granites and met sedimentary rocks. The older granites are composed of magmatite, biotite gneiss and banded gneiss. The general landscape is a product of sequence of incision and infilling which occurred in responses to past climatic changes which created a polycyclic landscape consisting of an upland plain, an

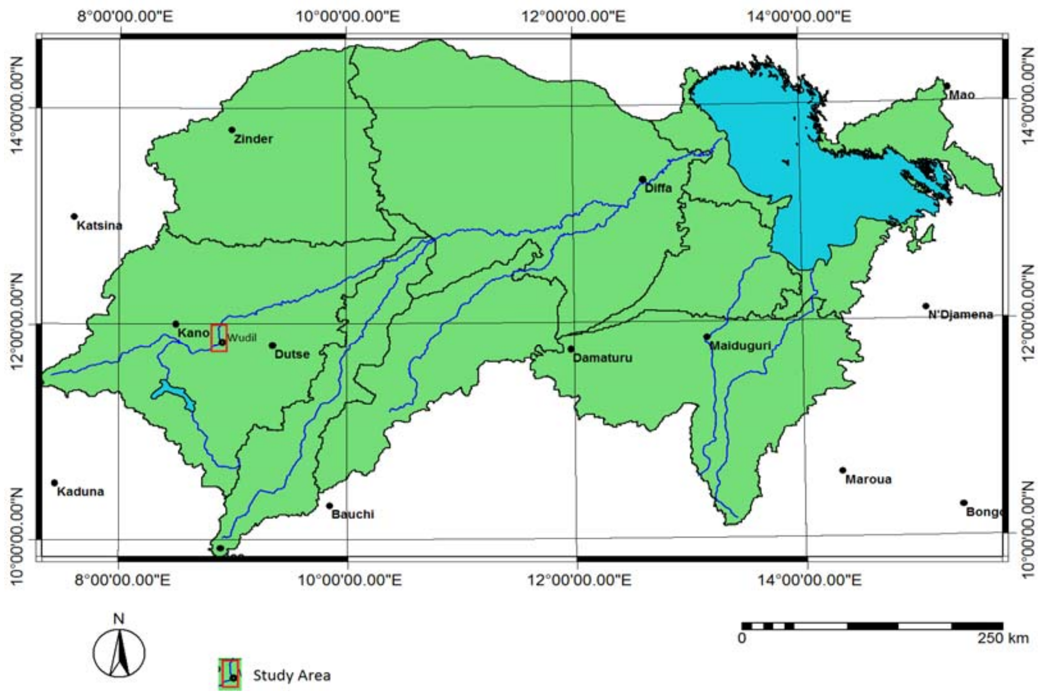

Fig. 2: Kano River at Wudil (study area) within the Kamodugu Yobe Basin

upper terrace, a lower terrace and the storm channel constituting the valley-bottom with slope units which slope at angles of 0^0 to $1.5^{0,}$ thus, the river channel is almost flat throughout. The typical relief is 300 m. The presence of lateritic out crop is ubiquitous along the river channels. Wind drift material covers both the regolith on the upland plains and the ancient alluvia on the terraces. The three sites in this study fall within the basement complex area.

RESULTS AND DISCUSSION

Changes in channel morphology: Width characteristics: The dominant form of sand mining in Kano River channel is wet pit mining in which diggers and shovels are used to remove sand from below the water table down to the bedrock floor of the channel. Mining points are carefully selected and observations indicate areas of natural slope where sand is deposited naturally are the areas of mining activity along the channel. Although sand mining in Kano river is manual in operation, in contrast to other places where heavy dredgers are used, the continuous removal over a long period of time results in the loss of considerable amount of sediments from the river system. The excavated sand is deposited as slurry without any sorting in small boats shown in Plate 1 and deposited on the bank of the river to drain in Plate 2 before eventually being loaded onto trucks to the market.

Table 1 shows the descriptive statistics of the width characteristics measured in the three sites and shows clearly the mining site is three times wider than

Plate 1: Boats collecting sand in Kano River

Plate 2: Sand deposited on the banks of Kano River

upstream and double the downstream site as well. One way analysis of variance between groups was conducted to explore further the impact of sand mining on the measured width between the three sites shown in Table 2. Preliminary assumption testing was conducted to check for normality and homogeneity of variance with no serious violation noted.

The result of the one way ANOVA in Table 2 provides sufficient evidence that there is an essential difference in at least one of the sites at 95% level of significance.

The wider channel in the mining site is a direct consequence of the mining activity which disrupts the structure and cohesion of the river bed. The constant digging to collect the materials at the bottom of the

Table 1: Descriptive statistics of the three sites (Width)

	N	Range	Min	Max	Mean	S.D	Variance
Upstream	50	2	50	52	50.480	0.707	0.500
Downstream	50	3	73	76	74.400	0.639	0.408
Mining site	50	2	110	112	110.90	0.763	0.582

Table 2: One-way ANOVA: Comparing the width of upstream, downstream and mining sites

Source	df	SS	MS	F	p value
Between-group	2	62478.2	31239.1	793.4	0.000
Within-group	48	1890.00	39.4000		
Total	50	64368.0			

Table 3: Descriptive statistics of the three sites (Depth)

	N	Range	Min	Max	Mean	S.D	Variance
Upstream	50	2	2	3	2.66	0.688	0.474
Downstream	50	2	2	4	2.72	0.671	0.451
Mining site	50	2	3	7	4.26	0.723	0.523

Table 4: One-way ANOVA: Comparing the depth of upstream, downstream and mining site

Source	df	SS	MS	F	p value
Between-group	2	20.400	10.20	3.61	0.035
Within-group	48	135.59	2.820		
Total	50	155.90			

channel is particularly damaging as it removes the river bed armoring thereby disrupting the river bed stability which is the most important aspect of a river system's ecology (Collins and Dunne, 1986; Kundolf, 1994; Kondolf *et al*., 2002; Pringle, 1997). It is known that natural stream channels develop the armoring along the bottom and sides over several years and the armoring protects the channel from erosion and if it is destroyed, even small rises in normal channel level can lead to erosion that widens the channel. A further cause of the widening channel in the mining site is the removal of riparian vegetation which weakens the channel bank leading to collapse as seen in Plate 3.

It has been observed in this study and elsewhere that the flattening of the river channel associated with the increased width resulting from mining results in the river water to spread out over a larger area creating a much shallower water depth than would normally be present and the isolated deep pools tend to fill with fine sand leading to shallow depth (Kondolf, 1994, 1997; Pringle, 1997).

A significant consequence of the widening channels in the mining affected areas is that widened channels have larger cross-sectional areas, so flooding exceeding bank-full capacity may be less frequent, since the effective capacity of the stream is increased (Kondolf, 1997).

Plate 3: Weakened Channel Bank due to removal of vegetation

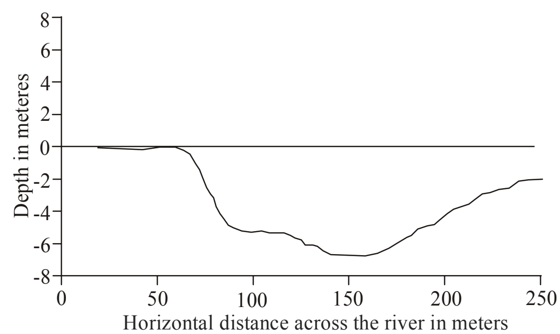

Fig. 3: Cross section of the mining site depth

Depth characteristics: The descriptive statistics of the depth characteristics of the three sites in Table 3 indicate uniformity between the upstream and downstream sites. The apparent uniformity in depth between the two sites is to be expected as the channel is eroded laterally more than vertically due to mining induced lateral erosion.

A particular reason for the uniformity of the depth in the study area is the fact that bedrock underlies Kano river channel. However, the result of the ANOVA in Table 4 provides sufficient evidence that there is an essential difference in at least, one of the sites at 95% level of significance.

A cross section of the three sites in Fig. 3 to 5 illustrates vividly the depth characteristics of the sites.Clearly all three sites are lower than the river bed depth. Specifically, the profile revealed that the mining site has attained a depth of 7 m lower than the riverbed depth, downstream it is 4 m lower, while it is 3m in the upstream site.

The significantly lower depth measured in the mining site is due to the fact that removal of a sizeable quantity of sand within the site results in the excessive movement of sand down slope to fill the hole within

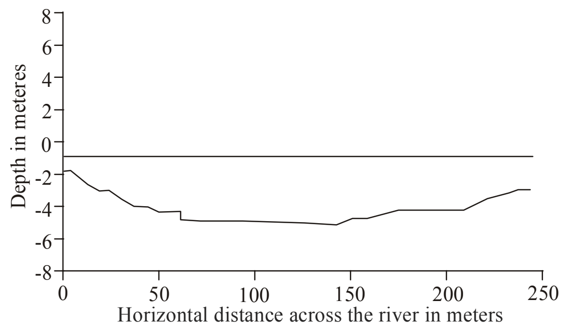

Fig. 4: Cross section of the upstream site depth

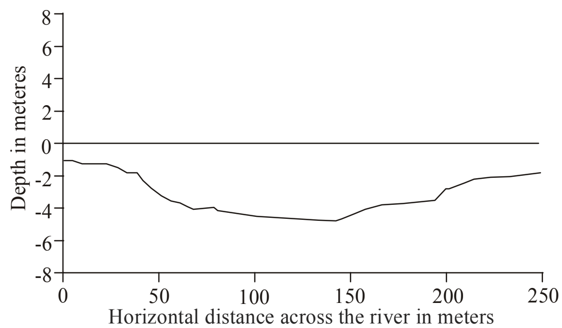

Fig. 5: Cross section of the downstream site depth

Plate 4: Braided Channels-in the mining site

the site. This results in downstream areas to have fewer loads to maintain normal stream channel structure because sand is intercepted at the mining site. This is accentuated in Kano River that has been dammed upstream where already a substantial supply to downstream site has been cut. This creates more power to the water in the area leading to increased water volume, speed and erosion which has resulted in a dramatic channel incision in excess of 4 m. The observed incision has occurred as a result of both, head cutting where, excavation of channel lowers the river bed, creating a nick point that steepens channel slope and increases flow energy towards the site or due to incision that occurs when sand removal increases the flow capacity of the channel. Similar observations were reported by Lu *et al*. (2007) among others. The observed depth in the upstream site is explained by the fact that as water flows over the mining pit, the dividing streamlines separate and converge at the upstream and downstream ends of the pit, respectively. Streamline separation causes eddy rollers and head cut erosion at the upstream end creating the deepened channel morphology observed. This effect is first felt immediately in the mined area, but as the erosion extends further downstream, the same impacts are repeated and the erosion becomes self-perpetuating (Brown *et al*., 1998; Kondolf, 1994, 1997; Kondolf *et al*., 2002; Kanehl and Lyons, 1992; Pringle, 1997). Such patterns have been observed in both natural streams (Kondolf, 1997; Neyshabouri *et al*., 2002; Rinaldi *et al*., 2005) and laboratory experiments (Lee and Chen, 1996; Neyshabouri *et al*., 2002).

Both conditions produce reduced stream flow velocities that results in sediments from upstream to deposit at the mining site which makes the channel to braid by forming numerous smaller channels as shown in Plate 4. Similar observation was reported by Rovira *et al*. (2005).

Ripple and pool characteristics: Field observations indicate variations between the three sites in ripple and pool characteristics. Compared to upstream, downstream pools were longer but upstream pools are deeper similar to what was reported by Brown *et al*. (1998). The upstream site is deeper due to the fact that even though more material is being washed in the mining area less sand is captured in these deep holes and instead, remains suspended in the water flow where it can be re-deposited in shallower areas downstream. These events appear prominent within the Kano River channel due to intermittent flow.

The expected spacing of riffles given as five to seven stream widths by Leopold *et al*. (1964), was not observe; so did not fit predictions based on bank-full widths from upstream. The riffle interval was however as expected in the mining site. The observed riffle lengths were similar in all three sites. It was also, observed that there were large areas of exposed bedrock in pools and riffles but fewer boulders in mining and downstream sites compared with the upstream sites similar to what was observed elsewhere by Collins and Dune (1986) and OWWRI (1995). There are pronounced meandering and cutoffs in the mining and downstream sites but none in the upstream site.

CONCLUSION

This study indicated that although sand mining in Kano river channel is done manually, it has none the less created major alterations to the physical structure of river channel. The depth characteristics indicated clearly a serious disruption in the form of the channel has occurred which manifest in the deep incision and creation of braided sections especially in the mining site, which ultimately results in a rapidly changing and unstable environment in the channel. This type of action is particularly serious in Kano River which is characterized with a high variability of water level. In order to capture the scale of change baseline data which capture geomorphic changes at basin level is crucial to improving our understanding of the impacts. Sediment transport modeling can also provide reach-scale aggradations and degradation patterns necessary to realistically evaluate the response of the channel to mining disturbances.

REFERENCES

Barksdale, R.D., 1991. The Aggregate Handbook. National Stone Association, Washington, DC.

Brown, A.V., M.M. Lytte and K.B. Brown, 1998. Impacts of gravel mining on gravel bed streams. T. Am. Fish. Soc., 127: 979-994.

Cao, Z. and G. Pender, 2004. Numerical modeling of alluvial rivers subject to interactive sediment mining and feeding. Adv. Water Resour., 27: 533-546.

Chang, H.H., 1987. Modeling Fluvial Processes in Streams with Gravel Mining in Sediment Transport. In: Thorne, C.R., J.C. Bathurst and R.D. Hey (Eds.), Gravel Bed Rivers. John Wiley and Sons Ltd., pp: 977-988.

Chen, D. and M. Liu, 2009. One-and two-dimensional modeling of deep gravel mining in the rio salado. Proceeding of the World Water and Environmental Resources Congress. ASCE, Kansas City, Missouri.

Collins, B. and T. Dunne, 1986. Gravel Transport and Gravel Harvesting in the Humptulips, Wynoochee and Satsop Rivers. Grays Harbor County, Washington. Report prepared for Grays Harbor County Planning and Building Department by Brian Collins and Thomas Dune, Geologists Dept. of Ecology. L-808 Seattle, Washington. (Location: MCM, Dept. of Ecology).

Cotton, G.K. and V. Ottozawa-Chatupron, 1990. Longitudinal channel response due to in-stream mining. Proceeding of the Specialty Conference of Hydrology Engineering. ASCE, New York.

Desprez, M., 2000. Physical and biological impact of marine aggregate extraction along the French coast of the eastern English Channel: Short-and long-term post-dredging restoration. ICES J. Mar. Sci., 57: 1428-1438.

Kanehl, P. and J. Lyons, 1992. Impacts of in-stream sand and gravel mining on stream habitat and fish communities, including a survey on the Big Rib River, Marathon County, Wisconsin. Wisconsin Department of Natural Resources, Research Report 155, Monona.

Kondolf, G.M., 1994. Geomorphic and environmental effects of instream gravel mining. Landscape Urban Plan., 28: 225-243.

Kondolf, G.M., 1997. Hungry water: Effects of dams and gravel mining on river channels. Environ. Manage., 21: 533-551.

Kondolf, G.M., P. Kahnel and H.Y. Lee, 2002. Freshwater Gravel Mining and Dredging Issues. Washington Department of Fish and Wildlife, Washington.

Lagasse, P.F., B.R. Winkey and D.B. Simmons, 1980. Impacts of gravel mining on river system stability. J. Waterw. Port C. Div., 106: 398-404.

Lee, H.Y. and S.C. Chen, 1996. Migration of rectangular mining pit composed of non uniform sediment. J. Chin. Inst. Eng., 19(2): 255-264.

Leopold, L.B., M.G. Wolman and J.P. Miller, 1964. Fluvial Processes in Geomorphology. Freeman, San Francisco, CA.

Lu, X.X., S.R. Zhang, S.P. Xie and P.K. Ma, 2007. Rapid channel incision of the lower Pearl River (China) since the 1990s as a consequence of sediment depletion. Hydrol. Earth Syst. Sci., 11: 1897-1906.

Nabegu, A.B., 2012. In-stream sand mining in Kano river: Implications for sustainable resource utilization. Proceeding of the 54th Annual Conference of the Association of Nigerian Geographers, Department of Geography, Kano University of Science and Technology, Wudil.

Neyshabouri, S.A., A. Farhadzadeh and A. Amini, 2002. Experimental and field study on mining-pit migration. Int. J. Sediment Res., 17(4): 323-331.

OWWRI (Oregon Water Resources Research Institute), 1995. Gravel disturbance impacts on salmon habitat and stream health. A Report for the Oregon Division of State Lands. Vol. 1: Summary Report, pp: 52.

Pringle, C.M., 1997. Exploring how disturbance is transmitted upstream: going against the flow. J. N. Am. Benthol. Soc., 16: 425-438.

Rinaldi, M., B. Wyżga and N. Surian, 2005. Sediment mining in alluvial channels: physical effects and management respectives. River Res. Appl., 21: 805-828.

Rovira, A., R.J. Batalla and M. Sala, 2005. Response of a river sediment budget after historical gravel mining (the lower Tordera, NE Spain). River Res. Appl., 21(7): 829-847.