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Shrinking and Sinking Deltas: Major role of Dams in delta subsidence and Effective Sea Level Rise



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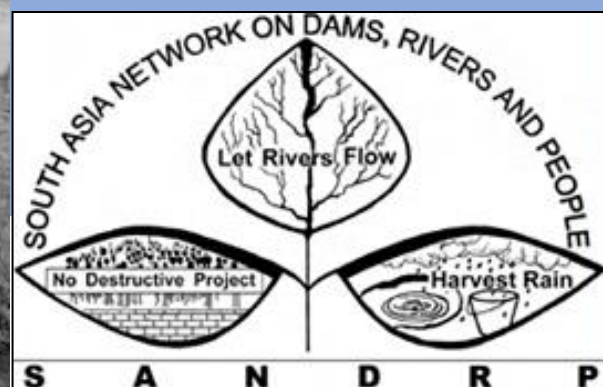
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Index

Executive Summary.....	1
1. Introduction.....	2
2. Delta Subsidence and Effective Sea Level Rise (ESLR).....	3
Box 1. Dams and sediments: Impacts upstream of the delta	
Box 2. Sediment flux of rivers Vs sediments deposited at the delta	
Box 3. Sediment flux and Effective Sea Level Rise	
3. Fluvial Sediments and Deltas in India.....	8
4. Deltas in Peril: Impact of damming on deltas in India.....	9
4.1 Krishna-Godavari Delta	
4.2 Cauvery Delta	
4.3 Narmada Delta	
4.4 Ganga-Brahmaputra Delta	
4.5 Indus Delta	
5. Conclusions.....	13
6. Recommendations.....	15
Bibliography.....	16

EXECUTIVE SUMMARY

The integral role of rivers in transporting sediments has been largely neglected. Nonetheless, it is the fluvial sediment which plays an important role in the geomorphology of the rivers, in the fertility of the floodplains, in nutrient balance of rivers and estuaries and in the formation of fertile and densely populated deltas. Close to half a billion people in the world live on or near deltas. Although constituting a relatively small proportion of landmass, deltas not only support huge populations but are important food and fish producing regions of the world and valuable, productive ecosystems which link inland waters and the marine environment.

But today, studies and ground reports are warning us that most of the deltas around the world are shrinking due to catastrophic sea level rise. And not all the blame can be put on climate change. According to several independent scientific studies, the major reason behind this effective sea level rise is delta subsidence. Our deltas are literally sinking, shrinking and are in a grave peril, some of which may not stand the pressures in the coming years. This will impact millions of people, major food producing regions as well as valuable ecosystems.

And the major reason behind sinking and shrinking deltas is sediment trapping by the dams built on the upstream rivers, which has resulted in oceans eroding and eating away deltas. Studies indicate that the reduced sediment load due to sediment retention by dams worldwide represents a volume equivalent to an area of about 7300 km² assuming a 10 m thick bed of sediments. In South Asia, during the past century, there has been over 94% reduction in Indus delta sediment, over 30% reduction in Ganga-Brahmaputra delta sediment, 94% reduction in Krishna's sediment, 95% reduction in Narmada, 80% reduction in Cauvery, 96% reduction in Sabarmati (annual sediment loads), 74% reduction in Mahanadi, 74% reduction in Godavari, etc.

The direct impacts of delta subsidence and effective sea level rise abetted by dams include inundation of coastal areas, saltwater intrusion into coastal aquifers, increased rates of coastal erosion, an increased exposure to storm surges, etc, in addition to the threat to food security, livelihood security, water security to millions and huge loss of biodiversity. These threats have implications for hundreds of millions of people who inhabit the deltaic as well as the ecologically sensitive and important coastal wetland and mangrove forests.

The current environmental governance surrounding dams does not identify or address this issue and hence does not attempt to mitigate it. **The report analyses the latest scientific studies in this field and puts together a picture that is disturbing and needing urgent attention. As Prof. Syvitski, Chair — International Geosphere-Biosphere Programme tells SANDRP: “We must learn to do better”.**

Note: Authors would like to thank Peter Bosshard (International Rivers) for his inputs and encouragement.

“We enjoy pushing rivers around”

- An early Hydraulic engineer in California (from Patrick McCully's *Silenced Rivers*, 1996)

“We tame mighty rivers”

- Sutej Jal Viduyt Nigam Limited, damming the entire Satluj Basin in India

“Water flowing to the sea is a waste”

- A view held by several water resource developers

1. Introduction

“Welcome to Anthropocene”¹, says James Syvitski, a leading oceanographer, geologist and hydrologist from Colorado University who has been studying subsidence of deltas. Some scientists are now placing Anthropocene, an era marked with human interference with natural systems, at par with geological epochs like Pleistocene and Holocene. It is manifested in many ways. Rivers and associated systems like deltas and floodplains possibly have had to face the maximum brunt of the Anthropocene.

Cutting edge scientists like Prof. Syvitski who study the changes in our deltaic systems seem to reach to a common conclusion: **Delta subsidence (sinking) is now the main driving force behind Effective Sea Level Rise for many coastal environments.** Delta subsidence is more influential than sea level rise related to global warming and many deltas are sinking much faster than the sea level is rising.

But why are deltas sinking? What is the main reason behind this subsidence which is eating away land and making millions of people more vulnerable?

It has been established that the main reason behind delta subsidence is drastically reducing sediments reaching the delta. Studies estimate that during the past century, there has been a 100% reduction in Colorado's sediment reaching the delta, 80% reduction in Indus, 94% reduction in Krishna's sediment, 95% reduction in Narmada's annual sediment load, 80% reduction in Cauvery, 96% reduction in Sabarmati's annual sediment load, 74% reduction in Mahanadi, 74% reduction in Godavari, 50% reduction Brahmani, etc.^{2,3}

But why are sediments not reaching the delta?

Almost unanimous agreement between scientists indicates that the reason behind this drastic decline in sediments is sediment retention by dams and reservoirs in the upstream⁴. (Walling and Fang (2003), Vörösmarty *et al.*, (2003); Syvitski *et al.*,(2005), Erisson *et al.*, (2005), Walling (2008), K Rao *et al* (2010), H Gupta *et al* (2012)). This has been reiterated in IPCC WG II Report, April 2014.⁵

Large reservoirs trap as much as 80% of the upstream silt. As a result of decades of dam building, most rivers are carrying much less sediment, and some rivers (like Krishna, Indus, Nile, and Colorado) transport virtually no sediment! In the last 50 years, the combined annual sediment flux of the large

¹ <http://www.anthropocene.info/en/home>

² Syvitski *et al* 2009

³ Harish Gupta *et al* , *The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers*, Journal of Hydrology, 2012

⁴ Walling and Fang (2003), Vörösmarty *et al.*, 2003; Syvitski *et al.*,(2005), Erisson *et al*, (2005), Walling (2008)

⁵ <http://www.ipcc.ch/>

Chinese rivers has been reduced from 1800 million tons (Mt) to about 370 Mt⁶ mainly due to frenzied dam building. The impact of dams and reservoirs on sediment retention has been so significant that the resultant reduced sediment load is equivalent to an area of 7300 km² assuming a 10 m thick bed⁷. IPCC Report (Assessment Report 5, 2014) refers that 34 rivers with drainage basins of 19 million km² in total show a 75% reduction in sediment discharge over the past 50 years due to reservoir trapping. Studies have also correlated proportion of sediment decrease with construction of mega dams in the catchment⁸.

2. Delta Subsidence and Effective Sea Level Rise (ESLR)

While this delta subsidence and sediment retention has several impacts on dense delta population and coastal ecosystems which offer important services, one of the most serious impacts is its direct role in Effective Sea Level Rise. Ericsson and Vorosmarty *et al*, 2012⁹, concluded that decreased accretion (accumulated increase in sediment over decades) of fluvial sediment resulting from sediment retention and consumptive losses of runoff from irrigation (also due to dams) are the primary determinants of ESLR in nearly 70% of studied deltas.

More and more scientists are concluding that climate related sea level rise has a ‘relatively minor influence on delta conditions’, as compared to anthropogenic reasons. As seen above, there is an almost unanimous agreement that dams are the most important factor influencing contemporary land-ocean sediment fluxes.¹⁰ Globally, greater than 50% of basin-scale sediment flux in regulated basins is potentially trapped in artificial impoundments of approximately 45,000 reservoirs (with dams 15 m high) (Vörösmarty *et al.*, 2003; Syvitski *et al.*, 2005) and sediment delivery to deltas has been reduced or eliminated at all scales.¹¹ Other reasons for delta subsidence include flow diversion by dams, sediment compaction due to groundwater abstraction, oil and gas exploration and mining, etc.¹²

Deltas, formed by centuries of accretion of rich sediment, are also one of the most fertile and densest populated regions across the world. It is estimated that close to half a billion people live on or near deltas, often in megacities.¹³ Although constituting a mere 5% of the total landmass, coastal regions sustain almost three-quarters of the world’s population and yield more than half of global gross domestic product (Vorosmarty *et al.*, 2009).

The direct impacts of ESLR and delta subsidence include inundation of coastal areas, saltwater intrusion into coastal aquifers, increased rates of coastal erosion, an increased exposure to storm surges, etc. These threats have implications for hundreds of millions of people who inhabit the deltaic as well as the ecologically sensitive and important coastal wetland and mangrove forests.

Already, some studies are ringing alarm bells. It is estimated that if no mitigation measures are undertaken and sediment retention continues, then by 2050, more than 8.7 million people and 28,000 km² of deltaic area in 33 deltas studied including Ganga-Brahmaputra, Indus, Krishna and

⁶ Harish Gupta *et al* *The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers*, Journal of Hydrology, 2012

⁷ *Sediment flux and the Anthropocene* James P. M. Syvitski and Albert Kettner **January** 2011 , published 31 , doi: 10.1098/rsta.2010.0329 369 2011 Phil. Trans. R. Soc. A

⁸ Harish Gupta *et al* , *The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers*, Journal of Hydrology, 2012

⁹ *Effective sea-level rise and deltas: Causes of change and human dimension implications*, Jason P. Ericson, Charles J. Vörösmarty, S. Lawrence Dingman, Larry G. Ward

¹⁰ Walling and Fang (2003), Vörösmarty *et al.*, 2003; Syvitski *et al.*, (2005), Erisson *et al.*, (2005), Walling (2008)

¹¹ *Sinking deltas due to human activities*, Syvitski *et al* 2009, Nature Geoscience

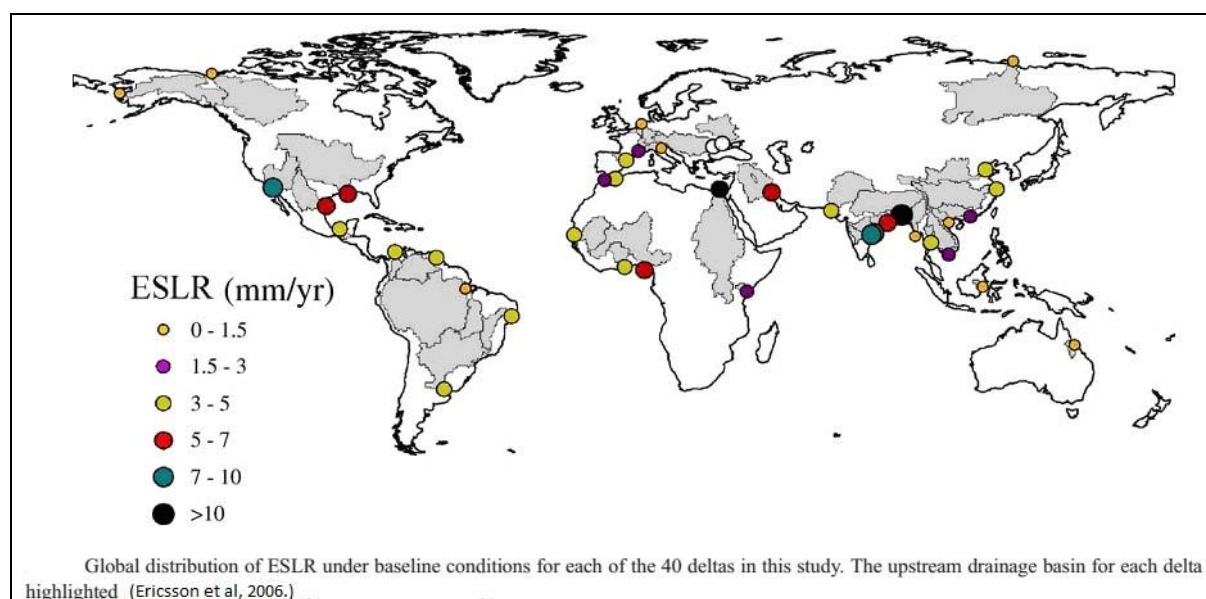
¹² *Sinking deltas due to human activities*, Syvitski *et al*, 2009, Nature Geoscience

¹³ *Sinking deltas due to human activities*, Syvitski *et al*, 2009, Nature Geoscience

Godavari could suffer from enhanced inundation and increased coastal erosion. In addition, a larger population and area will be affected due to increased flood risk due to storm surges¹⁴. Conservative estimates state that **delta area vulnerable to flooding could increase by 50% under the current projected values for sea-level rise in the 21st century and this could increase if the capture of sediment upstream persists and continues to prevent the growth of the deltas.**¹⁵

The Intergovernmental Panel on Climate Change (IPCC) projects that sea level will rise by another 21 to 71 cm by 2070, with a best estimate of 44 cm averaged globally. This will further compound impacts of delta subsidence and sediment trapping. So while Climate change may not be the primary driver behind delta subsidence, it will play an important role in worsening the impacts of existing subsidence.

Not all sediment flux in the river ends up in the delta. Some studies estimate that the proportion of sediment flux in the river and that which ends at the delta may even be 9:1 (Meade 1996). In this context, Extreme Flood Events seem to play an important role in the delivery of sediment to the deltas in river systems. But, it seems that even in the case of debilitating floods, sediment has not reached rivers in the deltas.¹⁶ In 2007–08 alone Ganges, Mekong, Irrawaddy, Chao Phraya, Brahmani, Mahanadi, Krishna and Godavari flooded with more than 100,000 lives lost and more than a million habitants displaced. But, most of the deltas that suffered from floods did not receive a significant input of sediment, and this lack of sediment can be attributed to upstream damming.¹⁷ Some studies demonstrate how mega dams trap sediment-laden water of major flood events too.¹⁸



¹⁴ Ericsson et al, 2006, *Effective sea-level rise and deltas: Causes of change and human dimension implications*

¹⁵ *Sinking deltas due to human activities*, Syvitski et al, 2009, Nature Geoscience

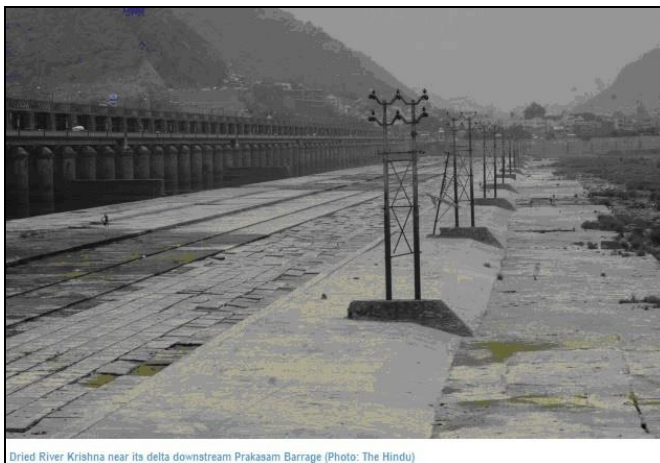
¹⁶ *Sinking deltas due to human activities*, Syvitski et al, 2009, Nature Geoscience

¹⁷ *Sinking deltas due to human activities*, Syvitski et al, 2009, Nature Geoscience

¹⁸ Harish Gupta, et al *The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers*

Professor James Syvitski (University of Colorado, Boulder, USA¹⁹), a leading Oceanographer who has worked extensively on delta systems around the world wrote a few words for SANDRP. He says:

*“A delta can form only where the sediment volume supplied from a river can overwhelm the local ocean energy (waves, tides, currents). Ocean energy is ceaseless. Engineering of our river systems, largely through the construction of upstream dams and barrages, has reduced this sediment supply. Consequently ocean energy has begun to reduce the size of our deltas, and coastal retreat is presently widespread. Deltas, once the cradle of modern civilizations, are now under threat — some deltas are in peril of lasting only the next 100 years. Sea level is rising due to ocean warming and glacier melting. Incessant mining of groundwater from below a delta’s surface, along with oil and gas extraction, further contribute to our disappearing deltas. At risk are the residences of more than 500 million people, the loss of biodiversity hotspots, major infrastructure (e.g. megacities, ports), and the rice and protein bowls of the world. Every year thousands of people drown due to storm surges and other coastal flooding. Sinking deltas are evidence of the magnitude of the human footprint on our planetary environment. **We must learn to do better.**”*



¹⁹ He is also Chair — International Geosphere-Biosphere Programme (ICSU), Executive Director, the Community Surface Dynamics Modeling System

Box 1. Dams and sediments: Impacts upstream of the delta

According to the International Commission on Large Dams (ICOLD), the world's dams have a total storage of 6800 km³. According to the [Chairman, ICOLD Sedimentation Committee](#), the accumulated sediment storage in world reservoirs has been evaluated as 1400Mm³ for 30 to 40-year-old dams on average, ie in the range of 40Bm³ per year, ie 0.6 % of the total storage per year. He estimates the total loss including downstream impacts of this sedimentation in dams at 17 Billion US Dollars annually. [SANDRP's studies](#) from India estimate that annual rate of sedimentation in Indian dams is about 1.95 Bm³ (Km³).

Thus, we are losing live storage capacity rapidly due to sediment retention. This storage capacity has been created at huge social, economic and ecological costs.

Sediment trapping by dams also affects regions upstream of the delta by:

- Reducing live storage of dam projects
- Increasing erosion immediately downstream of dams due to sediment-starved water. Silt free water has an increased capacity to erode river banks and flood plains in an effort to regain its equilibrium. This may lead to accelerated erosion in regions which have not experienced erosion before. For rivers like Brahmaputra which are already experiencing tremendous impacts of erosion, the problem will get magnified by upstream dams trapping silt and releasing silt-free water.
- Siltation in the upstream of reservoirs: Reservoir siltation leads to sedimentation in the upstream, affecting fish spawning sites, traditional fishing area etc. This has been experienced in Vidarbha region of India.



Above: Silted Panchet reservoir of the Damodar Valley Corporation Photo: The Hindu

Box 2. Difference between sediment flux of rivers, compared to sediments deposited at the delta

There is a significant difference between sediment flux of rivers, sediment trapped by dams and the sediment that is deposited at the delta.

According to Prof. Syvitski, there are many reasons for this. Sediment is stored in large river systems across many different time scales with little link between the original erosion of uplands and subsequent sediment discharge at river mouths. Ninety percent of the sediment eroded off the land surface is stored someplace between the uplands and the sea (Meade, 1996). Hence, much of the sediment that is presently being stored in reservoirs might not make it to the coastal zone.

Periodic sediment Pulses: *At the seasonal scale, sediment is stored in riverbeds and along their banks at low or falling discharge and is resuspended at high or rising discharges. Often sediment temporarily stored is washed out of the system before peak discharge is reached. At the decade-to-century time scale, sediment moves down the drainage system in a series of sediment pulses, and it may take decades for the sediment to reach the lowest reaches of the flood basin (Madej and Ozaki, 1996; Lisle et al., 2001).*

Due to the sediment cycle, which has many components which in turn depend on many natural events, a dam built may not immediately impact the sediment load of the delta. However, this will happen over time. By the same logic, dams built near river mouths (Barrages in India, across Indus in Pakistan, etc.,) may have a faster and more pronounced impact on delta.

Most of the sediment that reaches the coastal zone is the suspended load or wash load, which has been washed out of the hydrological network. However, bed material load of the river is left behind awaiting some extraordinary flood to carry further towards the coast. Eventually this coarse load is largely sequestered in floodplain and may not reach the delta. (Based on Syvitski et al, 2003)

Box 3. Sediment flux and Effective Sea Level Rise

For any delta, Effective sea Level Rise (ESLR) is a net rate, defined by the combination of sea-level rise, the natural gross rate of fluvial sediment deposition and subsidence, and accelerated subsidence due to anthropogenic reasons.

All natural deltas are formed by comparatively rapid deposition of sediment which exceeds rate of local sea-level rise, subsidence or the rate sediment can be removed by coastal erosive processes (Wells and Coleman, 1984). On a global scale, deltas started forming in the lower Holocene period when the sea level rise due to melt water started to slow down considerably. Thus the formation of deltas and their existence depends both on sea level rise as well as sediment deposition. The fragile equilibrium of both these has led to stabilization of prosperous and hugely populated deltas. (Based on Ericsson et al, 2006)

Today, both of these factors responsible for delta stability are affected by anthropogenic reasons.

Sea Levels are rising due to anthropogenic global warming and climate change. The levels are expected to rise by about 44 cms by 2070 (IPCC). Frequency and severity of storm surges affecting deltas is also on a rise. Most significantly, dams are trapping sediment, leading to lesser sediment reaching the deltas. These factors together are affecting the delta equilibrium compounding delta destruction.

3. Fluvial Sediments and Deltas in India

Rivers are not only conduits of water. They are a complex, moving systems carrying sediment, nutrients, organisms, ecosystems, energy, material and cultures in their wake.

There are three kinds of sediments: suspended, bed load and wash load. Sediments play a significant role in the river geomorphology, defining the river channel, its shape and structure. Sediment deposits form alluvial floodplains, deltas, levees, beaches, ox bow lakes and lagoons and creeks. Sediment load and its composition changes according to the river, the geological landscape it flows in, its length, flow, structure, etc. While much of the sediment is deposited by the river on its banks and channel, the delta of the river is primarily formed of rich sediments. Through this deposition, the river may form distributaries at its mouth, like in case of Ganga, Brahmaputra or Mahanadi systems. Ganga-Brahmaputra Delta, shared by India and Bangladesh is one of the largest delta systems in the world, spanning more than 100,000 km²²⁰ transporting more than one billion tonnes of sediments annually.²¹

Deltaic populations in shared rivers of India, Bangladesh and Pakistan: Population of Ganga-Brahmaputra-Meghana Delta is more than 147 million people with a population density of more than 200 people per km² (520 people per square mile), making it one of the most densely populated regions in the world . The Krishna Godavari twin deltas supports 9.26 million people inhabiting the 12,700 km² area at 729 persons per km², which is more than double the country's average.²² Cauvery delta supports 4.4 million people²³ while the Mahanadi Delta too supports millions. Only two districts of Cuttack and Jagatsinghpur have a population more than 3.7 million. (Census 2011). Indus Delta in Pakistan supports more than 900,000 people. In addition, the contribution of deltas to economics, food production, transport, ecosystem services etc., is immense, making it a very valuable ecosystem which deserves protection.



Farming in the Cauvery Delta, Tamilnadu, India (Photo: New Indian Express)

²⁰ <http://delta.umn.edu/content/ganges-brahmaputra-meghna-gbm-delta>

²¹ <http://www.iisc.ernet.in/currsci/apr252003/1041.pdf>

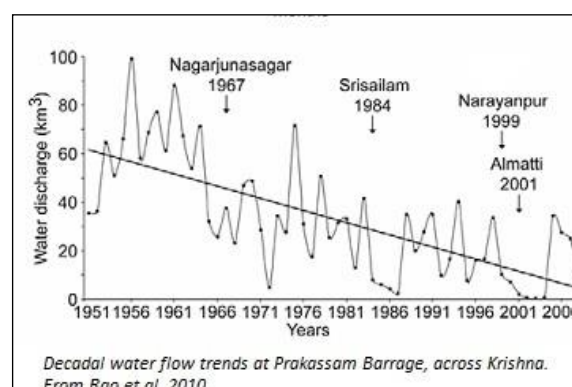
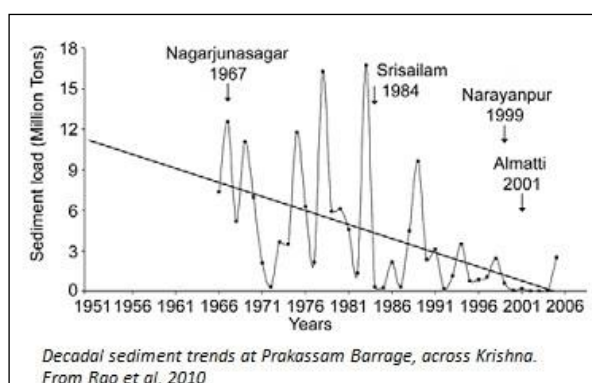
²² K Nageshwar Rao et al, 2010, *Impacts of sediment retention by dams on delta shoreline recession: evidences from the Krishna and Godavari deltas*, India Earth surface processes and landforms

²³ <http://www.infochangeindia.org/water-resources/features/the-cauvery-delta-an-economy-under-threat.html>

4. Deltas in Peril: Impact of damming on deltas in India

4.1 Krishna-Godavari Delta: In 2010, a team led by K Nageswar Rao of Dept of Geo Engineering, Andhra University, carried out an assessment of the impacts of impoundments on delta shoreline recession in Krishna and Godavari Delta.²⁴ **The study revealed a net erosion of 76 km² of area along the entire 336-km-long twin delta coast during the 43 years between 1965–2008 with a progressively increasing rate from 1.39 km² per year 1965 and 1990, to 2.32 km² per year during 1990–2000 and more or less sustained at 2.25 km² per year during 2000–2008.**

For **Krishna**, flows as well as suspended sediments in the delta have nearly reached zero. Suspended sediment loads decreased from 9 million tons during 1966–1969 to negligible 0.4 million tons by 2000–2005. Syvitski *et al* in their 2009 assessment place Krishna in the category of **“Deltas in Greater Peril: Virtually no aggradation and/or very high accelerated compaction.”**



In the case of the **Godavari** delta, there has been almost a three-fold reduction in suspended sediment loads from 150.2 million tons during 1970–1979 to 57.2 million tons by 2000–2006. Syvistki *et al* classify Godavari delta as **“Deltas in greater risk: reduction in aggradation where rates no longer exceed relative sea-level rise”**. H Gupta *et al* (2012) suggest that decline in historic sediments of Godavari post damming has been as high as 74%.

According to Dr. Rao, a comparison of data on annual sediment loads recorded along the Krishna and Godavari Rivers shows consistently lower sediment quantities at the locations downstream of dams than at their upstream counterparts, holding dams responsible for sediment retention. Reports based on bathymetric surveys reveal considerable reduction in the storage capacities of reservoirs behind such dams. Authors say: *“Sediment retention at the dams is the main reason for the pronounced coastal erosion along the Krishna and Godavari deltas during the past four decades, which is coeval²⁵ to the hectic dam construction activity in these river basins.”*

Impacts of this can be seen in destroyed villages like Uppada in Godavari delta, destruction of Mangrove forests and shoreline. Similarly Krishna delta is losing land at the rate of 82.5 ha per year, leading to destruction of mangrove forests and loss of land.

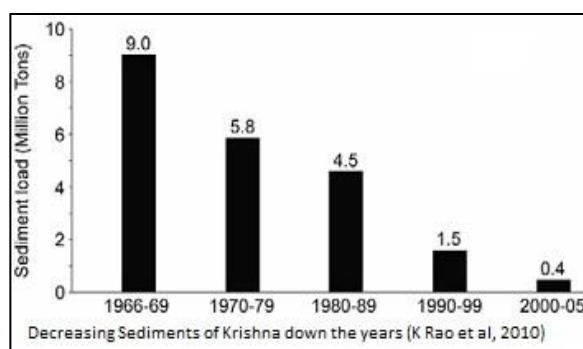
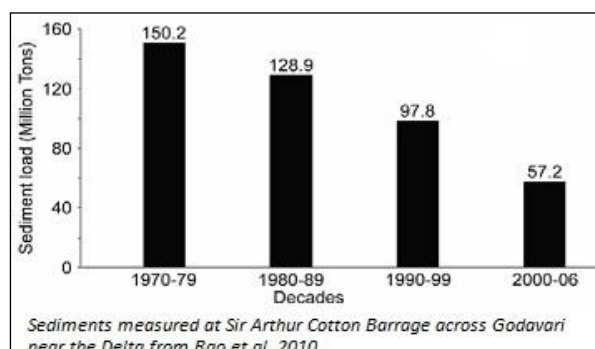
Dr. Rao told SANDRP in April 2014 that he has received absolutely no response to his research from the administration. Not even an acknowledgement of his papers.

²⁴ K Nageswar Rao et al, 2010, *Impacts of sediment retention by dams on delta shoreline recession: evidences from the Krishna and Godavari deltas*, India Earth surface processes and landforms

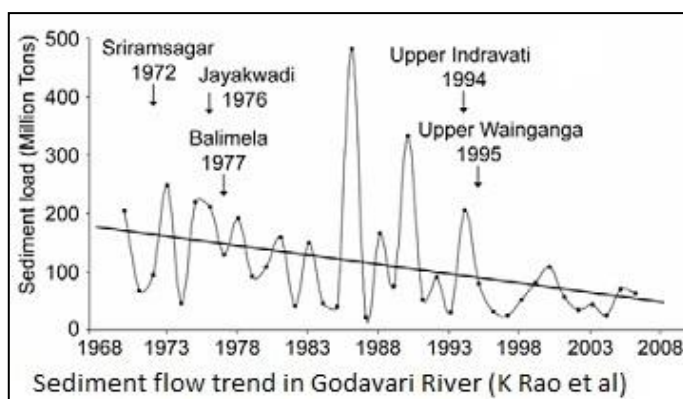
²⁵ Time period or age

The study concludes: *“If the situation continues, these deltaic regions, which presently sustain large populations might turn out to be even uninhabitable in future, considering conditions elsewhere, such as in southern Iraq, where the farmers downstream of dams across Tigris River in Iraq, Syria and Turkey are being forced to migrate to urban centres as the reduced river flows become overwhelmed by seawater.”*

A similar study by IWMI 26 concludes: *“Coastal erosion in the Krishna Delta progressed over the last 25 years (is) at the average rate of 77.6 ha/ yr, dominating the entire delta coastline and exceeding the deposition rate threefold. The retreat of the Krishna Delta may be explained primarily by the reduced river inflow to the delta (which is three times less at present than 50 years ago) and the associated reduction of sediment load. Both are invariably related to upstream reservoir storage development.”*



Krishna Basin Water Disputes Tribunal Award, though mentions dam siltation (it mentions that in 5 decades, Tungabhadra Dam has silted up to 22% of its capacity), does not say anything about flow for flushing sediments or its importance to the delta in Andhra Pradesh, or if the “minimum instream flow” recommended by the Tribunal will address this issue. This is a major limitation of the tribunal, when advanced studies have been conducted on the Krishna River delta condition and its relation to upstream dams has been established beyond doubt. Only at one place does it mention that to reduce siltation of the Almatti Dam, sluice gates should be opened when water is flowing above the crest. However, the Award states that issues like minimum in stream flows are not decided once for all and it is an evolving process. Let us hope that there is some space to address the issue of shrinking deltas through this.



In the upstream Maharashtra, more and more dams are under construction in the Krishna Godavari Basin. One of the proposed dams called Kikvi, at the headwaters of Godavari in Trimbakeshwar was cleared by the Forest Advisory Committee recently. Ironically, the proponent (Water Resources Department, Maharashtra and Nashik Municipal Corporation) justified this dam which will submerge

more than 1000 hectares of land, by stating that one more large dam close to Kikvi: Gangapur Dam is heavily silted up.²⁷ Rather than desilting Gangapur Dam, the administration wants to build one more dam.

Many dams in Krishna Godavari Basin in Maharashtra have been criticised for not contributing to increasing irrigation.²⁸ These dams are not only obstructing river flow, but are also acting as sediment traps. Unfortunately, the MoEF is not even considering impacts of sediments while appraising dams. In Karnataka, major projects are being undertaken by fraud, without environmental appraisal, violating Environment laws,²⁹ similarly in Andhra Pradesh, many projects are being pushed illegally without environmental appraisal and which involve huge corruption³⁰.

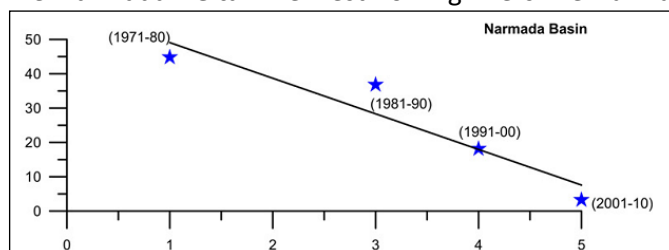
4.2 Cauvery Delta: Although detailed studies have not been carried out, there is a clear indication of salt water intrusion and delta erosion in this over developed basin, due to upstream dams. The saline-freshwater boundary map indicates a steady migration inland.

A study by Gupta *et al*, 2012, indicates that historical sediment flux of Cauvery was 1.59 million tonnes, which is now 0.32 million tonnes (average of 10 years) and hence, there is a whopping 80% reduction in sediment flux of the river.

Unfortunately, the **Cauvery Water Disputes Award Tribunal** between Karnataka and Tamilnadu does not even mention the word 'sediment' in its award. There has been no justification for 10 TMC feet (Thousand Million Cubic feet) water recommended by the Tribunal for Environmental purposes and its possible impact on sediment carrying (or even environment for that matter).

Pennar showed 77% reduction and Mahanadi showed 67% reduction in amount of silt reaching the delta in recent years. (Gupta *et al*, 2012)

4.3 Narmada Delta: The west flowing rivers like Narmada and Tapi do not form extensive deltas like



the east flowing rivers. Nonetheless, sediments from a huge river like Narmada play an important part in the stability of Narmada delta and villages and ecosystems around it.

Gupta *et al* (2012 and 2007) assessed daily water discharge and suspended sediment load data measured by CWC at two gauging stations, one upstream of the Sardar Sarovar dam (Rajghat), and another downstream of the dam (Garudeshwar).

Historical sediment discharge of Narmada was found to be 61 million tonnes and the current sediment discharge (average of last ten years of the study) was found to be 3.23 million tonnes, indicating a reduction of 95% sediment discharge.³¹ The presence of dam reduces 70–90% of coarse and approximately 50% of medium-sized particles on their way downstream, allowing them to settle in the reservoir. Comparative studies of average suspended sediment load at various locations on the Narmada River for more than two decades, show overall reduction in suspended sediment load in the river.

²⁷ <https://sandrp.wordpress.com/2013/07/26/forest-advisory-committee-does-not-clear-a-dam-project-in-western-ghats-of-nashik-affecting-nearly-1000-hectares-of-land-in-the-absence-of-relevant-studies-information-and-compliance/>

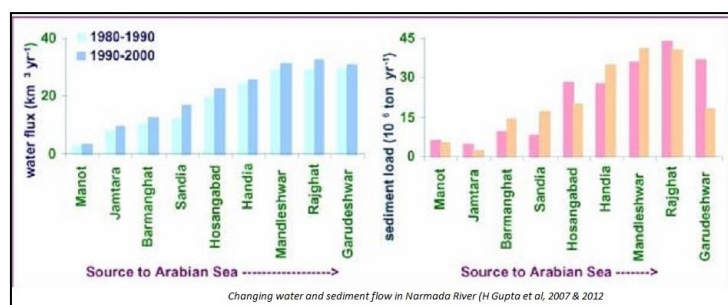
²⁸ <http://www.civilsocietyonline.com/pages/Details.aspx?194>

²⁹ <http://sandrp.wordpress.com/2014/03/12/tragedy-of-errors-environmental-governance-and-the-sonthi-lift-irrigation-scheme/>

³⁰ <http://sandrp.wordpress.com/2013/07/19/cag-blows-the-lid-off-massive-irrigation-scam-in-andhra-pradesh/>

³¹ Gupta et al, 2012, *The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers*, Journal of Hydrology

The study indicated 96% reduction in suspended silt flux in Sabarmati, 41% reduction in Tapi and 68% in Mahi.



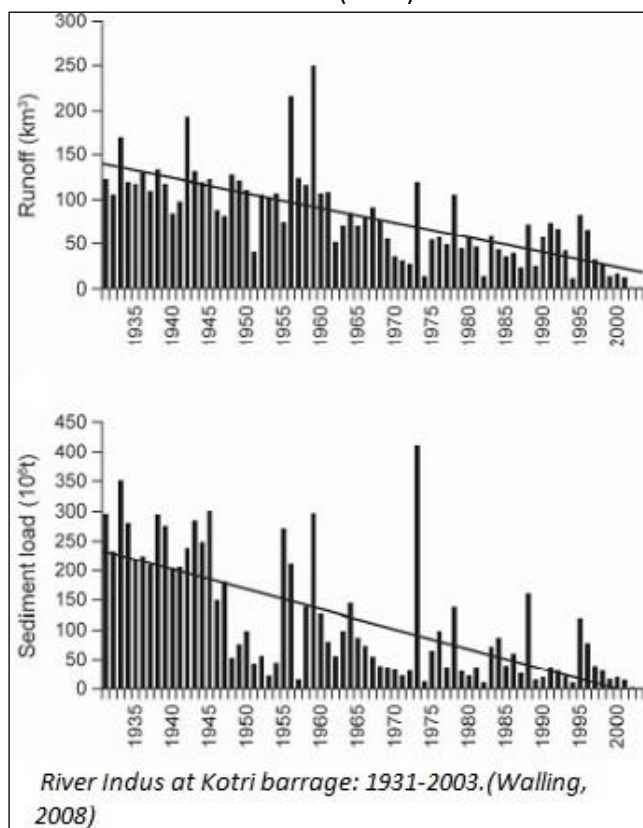
4.4 Ganga- Brahmaputra Delta:

Different studies put different values for individual and combined sediment load of the Ganga Brahmaputra system, which carries one of the highest sediment loads in the world. According to Islam (1999)³² Ganges and Brahmaputra rivers in

Bangladesh transport 316 and 721 million tonnes of sediment annually. Of the total suspended sediment load (i.e. 1037 million tonnes) transported by these rivers, only 525 million tonnes (c. 51% of the total load) is delivered to the coastal area of Bangladesh and the remaining 512 million tonnes are deposited within the lower basin, offsetting the subsidence. Of the deposited load, about 289 million tonnes (about 28% of the total load) is deposited on the floodplains of these rivers. The remaining 223 million tonnes (about 21% of the total load) is deposited within the river channels, resulting in aggradation of the channel bed at an average rate of about 3.9 cm/yr sediment.

Across the 20th Century, Syvitski *et al* suggest about 30% reduction of silt load in the river system. Gupta *et al*³³ suggest that the observed decrease in sediment load could be due to construction of several mega dams in the Ganga basin, closure of Farakka barrage (1974) and diversion of sediments laden water into the Hooghly distributary. They also caution that dams in Ganga and Brahmaputra can worsen the situation.

4.5 Indus Delta: Inam *et al* (2007) assessed annual sediment loads of the Indus river at Kotri Barrage



(270 km upstream from river mouth) during the last 73 years. The study indicates that annual sediment load of the Indus river has reduced drastically from 193 Mt (between 1931 and 1954) to 13 Mt (between 1993 and 2003). According to them, construction of three large dams on the Indus river, namely Kotri Barrage, Mangla and Terbela led to this situation causing annual water discharge to reduce from 110 km³ to 37 km³, with disastrous impacts on the delta ecosystem and population.

Inam states : "Currently the Indus river hardly contributes any sediment to the delta or Arabian Sea."

The active delta is reduced from 6200 km² before construction of dams to 1200 km². The sea water has travelled upstream upto 75 kms, combined loss of freshwater and sediment has resulted in loss of large areas of prime delta agricultural land and

³² Islam et al, The Ganges and Brahmaputra rivers in Bangladesh: basin denudation and sedimentation, 1999, Hydrological processes

³³ Harish Gupta et al, The role of mega dams in reducing sediment fluxes: A case study of large Asian rivers, Journal of hydrology, 2012

submergence of several villages in the coast. This has caused desertification and displacement of several hundred of thousands of local residents. Study of records and bathymetric maps from 1950 indicate widespread coastal retreat...The life on the delta is dependent on availability of freshwater and sediment. Severe reduction of both as a result of dams and barrages and associated structures in the upstream has resulted in pronounced erosion in parts of the delta and reduction in mangroves. Environmental studies to be extended to the entire Indus ecosystem from the mountains to the Arabian sea."

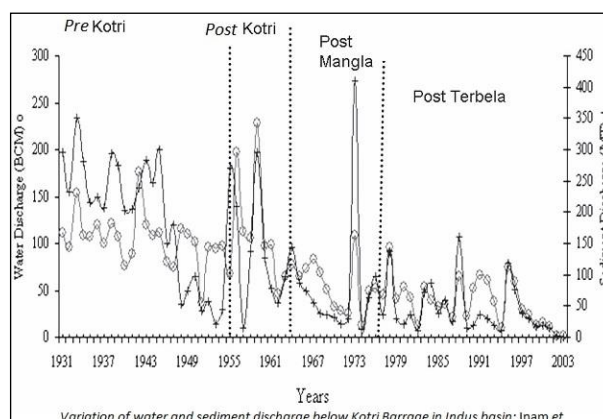
5. Conclusions

- It is clear that deltas and dependant populations and ecosystems have suffered due to near total ignorance about the impact of dams on sediment and deltas and if immediate action is not taken then, this will impact a huge population and a large eco-region in Indian subcontinent, as elsewhere.
- The impacts of nutrient rich sediment retention and flow reduction is not limited to the delta, but has also affected marine fish production³⁴
- The issue of impact of a dam on the sediment regime of the river is not being studied or considered at all while conducting Environmental Impact Assessments of projects, appraising the project for options assessment, environmental clearance, cost benefit analysis or through post clearance monitoring and compliance.
- Sediment release and sediment transport through rivers is not being raised in trans-boundary river negotiations.
- Looking at the severity of the issue and its far reaching impacts on millions of people in India and across the world, there is a need for adopting urgent and strong mitigation measures against sediment trapping in dams.
- It has to be remembered that for older dams, older hydropower projects and most irrigation projects, there is no mechanism available to flush the accumulated silt.
- Sediment retention also reduces the life of the dam, while starving the river and delta in the downstream of sediment. **As per a study by SANDRP in 2006, India may be losing 1.95 Billion Cubic Meters of Storage capacity of its reservoirs annually.**³⁵ This implies that the rivers are losing at least that quantity of sediment annually.

The frantic dam activity in Indian Himalayas at this moment will have a serious impact on Ganga Brahmaputra Delta in India and Bangladesh and Indus Delta in Pakistan. There

is an urgent need to, firstly, acknowledge these links, assess the impacts, include them in cost benefit and options assessment, address the issues and implement mitigation measures, where relevant, abandon the projects where impacts are unacceptable projects unviable.

In case of the **Ganga Brahmaputra delta**, recent studies have indicated that the main source of sediment in the river is the Himalayas³⁶. Of the entire sediment load of Ganga catchment (This study assumed it to be 794 million tonnes/year), 80+/-10 % comes from High Himalayas and 20+/-10 % comes from Lesser Himalayas.



³⁴ Drinkwater *et al* 1994

³⁵ http://sandrp.in/dams/reservoir_siltation_in_india0906.PDF

³⁶ R.J. Wasson, *A sediment budget for the Ganga–Brahmaputra catchment*, Current Science, 2003

Bumper to bumper dam/ hydropower project building is occurring in almost all of the Himalayan states in India, which is poised to make Indian Himalayas most densely dammed region in the world. All of these dams are located in the downstream of the Greater and straddling Lesser Himalayas and can together have a tremendous impact on Ganga's sediment load. Uttarakhand is planning and building nearly 336 Hydroelectric projects,³⁷ while Sikkim and Himachal Pradesh too are building hundreds of hydro projects. Arunachal Pradesh intends to dam most of its rives to produce hydropower.

No studies on impact of these projects on sediment regime of the rivers are being carried out for; neither does the MoEF insist that projects will not be cleared unless such studies are carried out. Even Cumulative impact assessments are not assessing this aspect.

Some stark examples:

The Cumulative Impact Assessment Report of the Upper Ganga Basin in Uttarakhand³⁸ (where more than one hundred dams are planned and under construction back to back) was done by IIT Roorkee. This cumulative impact assessment did not study any cumulative impacts due to reduced silt load of the river following major dam push.

The **Lohit Basin Study** done by WAPCOS³⁹ which involves more than 12 dams across the Lohit River, one of the three main segments that form Brahmaputra, does not mention anything about impacts of dams on sediments. The only thing it states is very worrying : *“Due to substantial storage capacity, the Demwe Upper reservoir will have high sediment retention capacity and a large proportion of sediments carried by the Lohit River will get settled in the reservoir.”*

Siang Basin Study⁴⁰ (by RS Envirolinks Pvt Limited), which involves three mega dams across the main stem Siang, completely obliterating free flowing stretches in the river, in addition to 42 hydropower dams, does not mention anything about sediment regime, although being specifically asked to address this issue by the Expert Appraisal Committee, Union Ministry of Environment & Forests (MoEF).

1500 MW Tipaimukh Mega Dam near Bangladesh Border, which has received Environmental Clearance from MoEF does not study the impacts of sediment retention on downstream Bangladesh, and this concern has been raised by the groups in that country. The Environment Management Plan of this project which can submerge 25000 hectares of forests does not even mention the word “sediment”.

The bumper to bumper dam building activity in Himachal Pradesh in **Satluj, Beas, Chenab and Ravi**⁴¹ rivers will have a major impact on silt load reaching the Indus river Basin and the Indus Delta in Pakistan. However, none of the EIAs or EMPs mention any impact of the dams on the sediment regime of the river.

In conclusion, although the risks of delta subsidence, effective sea level rise and its impact on a huge population and ecosystems has been established, these risks are being entirely ignored in the current governance surrounding rivers and deltas.

³⁷ <http://sandrp.wordpress.com/2013/07/10/uttarakhand-existing-under-construction-and-proposed-hydropower-projects-how-do-they-add-to-the-disaster-potential-in-uttarakhand/>

³⁸ http://www.sandrp.in/hydropower/Pathetic_Cumulative_Impact_Assessment_of_Ganga_Hydro_projects.pdf

³⁹ http://sandrp.in/rivers/Lohit_Basin_Study_by_WAPCOS_A_mockery_of_e-flows_and_cumulative_impacts.pdf

⁴⁰ <http://sandrp.wordpress.com/2014/02/18/cumulative-impact-assessment-study-of-siang-basin-in-arunachal-needs-urgent-improvement/>

⁴¹ <http://infochangeindia.org/environment/analysis/bumper-to-bumper-dams.html>

National Centre for Sustainable Coastal Management It is unfortunate to see that MoEF's National Centre for Sustainable Coastal Management, supported by MoEF and World Bank does not allude to this issue or raise it through any publications.⁴² In conversation with SANDRP, Director R. Ramesh said that the center may look at these issues in the future. However, its publications on National Assessment of Shoreline Changes on Tamilnadu and Odisha⁴³ do not mention upstream dams, although robust evidence exist that Cauvery delta and Mahanadi, Brahmani and Baitarni deltas are eroding due to sediment retention. Let us hope this institute will try to highlight the impact of dams on deltas with the seriousness it deserves.

6. Recommendations

1. Urgently study impacts of sediment retention by dams on delta population and ecosystems: MoEF, Ministry of Rural Development and Urban Development should conduct an in-depth study to understand the scale of the problems and the extent of affected people and ecosystems due to sediment impoundment by upstream dams.

2. Urgently study the optimal level of sediments (and water regime) needed for stabilising deltas and reducing subsidence.

3. Urgently institute a study to assess the extent of sediment and flows needed to be released from upstream dams and feasibility of such releases on regular basis, mimicking the river's hydrograph. Where dams have sluice gates, these should be opened in monsoons where feasible, to allow sediment flushing. Even in dry and stressed river basins like Colorado in the United States, such high releases for redistributing sediments have been conducted in the 1990s and again in 2013 with proper planning and impact assessment.⁴⁴

4. In Krishna and such other basins, where delta subsidence, coastal erosion and related impacts like salinity intrusion and storm surges has reached serious proportions, specifically problematic dams should be considered for decommissioning.

6.1 Environmental Appraisal Process

- Study of impact on sedimentation and siltation should be a part of the environmental impact assessment, environmental appraisal and clearance process.
- There should be a separate section in EIA for e-flows and sedimentation studies. Similarly such studies should be mandatory part of cumulative impacts, carrying capacity and basin studies.
- More dams in basins which support large deltaic populations and those having significant impacts of sediment retention by reservoirs should not be cleared.

Let us hope that this chronically neglected issue receives the attention it deserves. Delta subsidence and ESLR due to upstream damming again highlights the complex and interconnected nature of the riverine ecosystem. The environmental governance in India (as also South Asia) surrounding rivers has been treating rivers with an extremely piecemeal approach. It is clear that with the herculean challenges we face now, such an approach is no longer affordable.

⁴² <http://www.ncscm.org/>

⁴³ http://ncscm.org/sites/default/files/odisha_factsheet.pdf

⁴⁴ <http://www.usbr.gov/uc/rm/gcdHFE/2013/>

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...especially in the part called Delta, it seems to me that if the Nile no longer floods it, then, for all time to come, the Egyptians will suffer

Herodotus, History, c 442 BC (stated in Patrick McCully's Silenced Rivers)



Sediment-laden waters of River Elwha reaching the coastal waters after Elwha Dam Removal. (<http://gallery.usgs.gov/>)

Cover photo: With thanks from The Hindu and India Environment Portal

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