Sedimentation of Reservoirs in India

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ABSTRACT

Dams have always been envisaged as the lifelines of modern development and it is now felt that these are encountered with the major problem of Siltation. Siltation poses a big question on the sustainability of Basin Management. The paper describes the importance of control of sedimentation as it is an Invisible Water Source. The basin wise data for India for around 370 reservoirs which make up for around 8% of the total reservoirs in India is studied. The data predicts the state of affairs in various basins in India and provide comparative position of the sedimentation of reservoirs in the Basin. An analysis is being done to link urbanization of the basins with the sedimentation of the reservoirs. The results are important for making policy level decisions for tapping the invisible source of water.

Keywords: sedimentation, reservoirs, siltation, basin, sustainability

1. Sedimentation of Reservoirs

Dams have always been envisaged as the lifelines of modern development and this can be seen in the optimism and passion with which our former Prime Minister Jawaharlal Nehru's famous endorsement of them as the "temples of modern India." It was felt that the construction of large dams would solve many problems of India. It would result in generation of electricity, provide water for irrigation for farmers, supply water to households and industries. Main purpose of launching multipurpose river projects in India was to combine development of agriculture and village economy with rapid industrialisation and urbanisation. However, with time these temples of Modern India, encountered the major problem of Siltation. Siltation poses a big question on the sustainability of Basin Management.

2.River basins hydro-sedimentology

The siltation of the Reservoir is Hydrological that is Sediment yield and Hydraulic due to sediment tapping. Soil erosion is integrally linked to rainfall, land degradation, and excessive soil loss. Accelerated erosion due to anthropogenic factors- which include human activity viz. Agricultural activities, urbanisation, road and highway construction, mining operations, and altering runoff conditions and river control works have accelerated erosion. It is not uncommon these erosion rates have increased by more than 100 times that of the geological erosion. Landslides and debris flows may be the major accidental sources of sediment production. The sediment yield from a river basin reflects only part of the sediment eroded from within the basin that reaches the basin outlet

River basin is the specific study site to comprehend the sediment dynamics of river systems. The watersheds, sub basins contribute the sediments and provide a proper platform to diagnose and understand and predictions of sediments in the Reservoirs of the basins. The main component that relates to the sedimentology in the basin is the hydrological cycle, and breaking of the kinetic energy of raindrops, as the transferrer of the sediments.

The rate at which a reservoir siltsup depends on the amount of silt carried by the river which feeds it and that, in turn, depends on the rate of soil erosion in the river's catchment area.

Where that catchment is forested, the soil is not easily eroded due to the network of roots which underlies the forest floor and is also protected from the effects of wind and rain erosion by the forest canopy above. Sediment transport measure up to the Reservoir siltation in the Basin. The sediment reaching to the control point depend on the size of the Drainage Basin. From this perspective, the study of both water erosion potential and sediment transport estimation methods constitute important tools in order to support the analysis of hydraulic and hydrological impacts on watersheds and consequently to basins. The sediment delivery rate (SDR) is considered as a simple approach that allows to estimate sediment yield from watersheds. Hydro-sedimentological curves, suspended and deposited sediment measurements, and hydro-sedimentological models are useful in correct assessment of the sediment load generated in the basin.

The sediment load carried by some rivers is indeed very heavy, while the rivers in the Indian peninsula like the Krishna and the Godavari carry about 100 p.p.m., the silt carried by the Ganga often exceeds 2,000 p.p.m. In the Kosi, silt content is much larger, being 3,310 p.p.m. Some of the rivers in other countries also have heavy concentration of silt. The Mississippi river has 1,750 p.p.m. while the Nile has 1,500 p.p.m. The Yellow river in China carries 240,000 p.p.m. The flashy streams of the Siwalik hills of the Himalayas, carry large amount of loose sandy soils in Hoshiarpur, Jullundur and Ambala districts.

3. Indian River Basins

Rivers are dynamical systems with alternating patterns of sedimentation and erosion. A sediment budget is a most valuable tool for taking measures in river management that deal with sediment dynamics effectively. The Ganga and Brahamputra river Basins are characterised by high water flow, high relief, large catchment areas, and greater instability, involving landslides and earthquakes. Their geology is dominated by unconsolidated rocks of younger formations. In contrast the peninsular river Basins are typified by relatively low water flow, low relief, smaller drainage areas and an older and more stable geology which affect the magnitude and nature of sediment transport. Each Basin in India is unique in the production of the sediments point of view. The main source of sediments in the Reservoir remain erosion, sediment yield and deposition of sediments. The quantity of the sediments depends mainly on the geology and geomorphology of the basin, rainfall in the basin, river discharges, special variability's, Urban activities- density of population, developed industry, intensive agriculture, industrial history and tradition in mining. The size of the sediments depends on the characteristics physical weathering in the basin. It may be interesting to note that the annual sediment load of Ganga and Brahmaputra Basin constitute around 10% of the world's total sediment load in rivers!

Indian River Basin characteristics

CWC BASIN CODE	Name of Basin	Drainage Area 10^5 km^2	Run Off 10^9 m^3/year (BCM)	Storages BCM	Number of Large Dam Reservoirs
1	Indus	3.212	73.31	16.232	54
2A	Ganga (Upto Border)	8.6	525	56.326	915
2B	Brahmaputra (Upto Border)	1.94	537	2.5131	21
2C	Barak etc. (Upto Border)	0.42	48.3	9.891	5
3	Godavari	3.12	110	43.4515	1317
4	Krishna	2.58	78.12	54.807	786
5	Cauvery	0.81	12.37	9.098	106
6	Pennar	0.55	6.32	5.079	71
7	East flowing rivers between Mahanadi to Pennar	0.866	22.52	3.857	75
8	East flowing rivers between Pennar and Kanyakumari	1.00	16.46	1.456	72
9	Mahanadi	0.41	66.88	14.52	266
10	Brahmani and Baitarani	0.28	28.48	6.25	60
11	Subernarekha	0.29	12.37	2.459	36
12	Sabarmati	0.22	3.81	1.686	60
13	Mahi	0.25	11.02	5.167	169
14	West flowing rivers of Kutch and Kathiawar including Luni	3.21	15.1	6.87	483
15	Narmada	0.89	45.64	24.45	330
16	Tapi	0.49	14.88	10.695	522
17	West flowing rivers from Tapi to Tadri	0.56	87.41	17.098	283
18	West flowing rivers from Tadri to Kanyakumari	0.56	113.53	12.439	88
19	Area of Inland drainage in Rajasthan	0.31		0	7
20	Minor river basins drainage to Bangladesh& Burma	0.36	31	0.14	3

4. Basin wise Reservoir Sedimentation Position in India

Presently, India has 5500 plus large dams in operation and 447 large dams under construction having gross storage of more than 300 billion cubic meter. Approximately 80% of these existing dams are more than 25yearsold.Theirhealthneeds to be improved considering sediment management in order to ensure reservoir life and safety. CWC published the compendium of the Reservoir Sedimentation in 2015 for a data compiled for 243 Reservoirs. Since 2015, the Water Shed & Reservoir Sedimentation (WS&RS) Directorate, CWC has been compiling information about the Reservoirs around the country and the information is being complied Basin wise and linked with sediment concentrations in rivers. The collected information however represents only 8% of the total dams in India and all analysis are still in approximations.

The average annual rate of sedimentation of reservoirs in India from the catchments is 16.58 (Th.Cu.m/ Sq.km./Yr). The average rate is very high in West Flowing Rivers below Tapi Basin and in the Himalyan Rivers. On the study for 100 important reservoirs it has been found that the Average design rate of siltation of reservoirs 0.53 (Th.Cu.m/ Sq.km./Yr) has been surpassed by the observed rate of siltation at 1.27(Th.Cu.m/ Sq.km./Yr) with decrease in the Trap efficiency. Another study of 148 Reservoirs has indicated that around 13.38% of the Live storage has been lost to sediments in all Basins. From the collected data of reservoirs in India in CWC, the Basin wise findings are compiled as follows:

CWC BASIN CODE	Name of Basin	Built Up Storages BCM	Sedimentation Data Available for Reservoirs(No.) in CWC	Storage Capacity of Observed Reservoirs in MCM	Average Years of Service as on 2019	Average % loss of Gross storage in the Reservoirs
1	Indus	19.43	9	19.41	25	35
2A	Ganga (Upto Border)	56.326	29	34055	56	15
2B	Brahmaputra (Upto Border)	2.5131	10	275	21.4	16
3	Godavari	43.4515	50	17445	35	7.6
4	Krishna	54.807	53	51.198	55	28
5	Cauvery	9.098	38	10231	52.5	11
9	Mahanadi	14.52	11	13687	45.9	11.8
10	Brahmani and Baitarani	6.25	3	5146	36	7.8
11	Subernarekha	2.459	4	395		8.1
12	Sabarmati	1.686	6	2064	52.8	6.3
13	Mahi	5.167	11	7219	50.7	11.55
14	West flowing rivers of Kutch and Kathiawar including Luni	6.87	49	8639	51	37.3
15	Narmada	24.45	6	7352	31.6	10.5
16	Tapi	10.695	8	9143	74	14

17	West flowing rivers from Tapi to Tadri	17.098	12	2794	51	8.98
18	West flowing rivers from Tadri to Kanyakumari	12.439	50	14084	60	6

The Loss of the Reservoir Capacity is high in upstream part of the Basin. The upstream dams mostly work as the sediment retention dams and save the life of major reservoirs.

For many Indian rivers, the pattern of erosion and sediment transport has been significantly affected by human activities. On linking of the Reservoir sedimentation to erosion due to human activities Small basins like Mahi, Tapi, Sbarmati, West flowing rivers of Kutch and Kathiawar including Luni and Minor river basins drainage to Bangladesh & Burma appear to be at major risk due to population boom and economic activities.

CWC BASIN CODE	Name of Basin	States with Drainage Area in Sq. Km.	Population Growth of the Basin 1961-2011 (40 Years) with interpolated prediction to 2019
1	Indus	Jammu & Kashmir- 193762(60%) Punjab- 50304 (15.96%) Himachal Pradesh- 51356 (16%) Haryana- 9939 (3%) Rajasthan- 15814 (5%) Chandigarh- 114 (0.04%) Total- 321289	Up to 2011- 217.508% Predicted to 2019- **252.309%**
2A	Ganga (Upto Border)	Uttar Pradesh- 241392 (28%) Rajasthan-112496 (13%) Madhya Pradesh- 181066 (21.01%) West Bengal- 71489 (8.3%) Uttrakhand- 52988 (6.1%) Jharkhand- 50389 (5.85%) Chattisgarh- 17908 (2.07%) Delhi- 1484 (0.17%) Bihar-93580 (11%) Haryana- 34343 (4%) Himachal Pradesh- 4317 (0.5%) Total- 861452	Up to 2011- 199.343% Predicted to 2019- **231.238%**
2B	Brahmaputra (Upto Border)	Assam- 70634 (36.3%) Arunachal Pradesh- 81414 (42%) West Bengal- 12585 (6.4%) Meghalaya- 11667 (6%) Nagaland- 10803(5.6%) Sikkim- 7300 (3.7%) Total- 194370	Up to 2011- 260.879% Predicted to 2019- **302.62%**
2C	Barak etc. (Upto Border)	Meghalaya- 10650 (26%) Mizoram- 8866 (21%) Tripura- 4688 (11%) Manipur- 9567 (23%) Assam- 7224 (17%) Nagaland- 728(2%) Total- 41723	Up to 2011- 216.267% Predicted to 2019- **250.871%**
3	Godavari	Andhra Pradesh- 73163(23.39%) Karnataka- 4405 (1.40%) Madhya Pradesh- 5220 (1.6%)	Up to 2011- 169.27% Predicted to 2019- **196.353%**

		Maharashtra- 152199 (49%) Orissa- 17752 (5.6%) Chhatisgarh- 60035 (19%) Puducherry- 38 (0.01%) Total- 312812	
4	Krishna	Andhra Pradesh-76252 (29%) Maharashtra-69425 (27%) Karnataka- 113271 (44%) Total- 258948	Up to 2011- 158.843% Predicted to 2019- **184.258%**
5	Cauvery	Karnataka- 34273 (42.23%) Tamil Nadu- 43856 (54.04%) Kerala- 2866 (3.53%) Puducherry- 160 (0.20%) Total- 81155	Up to 2011- 132.774% Predicted to 2019- **154.018%**
6	Pennar	Karnataka- 6937 (13%) Andhra Pradesh-48276 (87%) Total- 55213	Up to 2011- 138.175% Predicted to 2019- **160.283%**
7	East flowing rivers between Mahanadi to Pennar	Andhra Pradesh- 60863 (70%) Orissa- 25780 (30%) Total- 86643	Up to 2011- 136.296% Predicted to 2019- **158.103%**
8	East flowing rivers between Pennar and Kanyakumari	Tamilnadu- 76926 (77.52%) Andhra Pradesh- 16478 (16%) Karnataka- 6256 (6%) Puducherry- 479 (0.48%) Total- 100139	Up to 2011- 120.80% Predicted to 2019- **140.128%**
9	Mahanadi	Madhya Pradesh- 154(0.1%) Chattisgarh- 74982(52.96%) Orissa- 65580(46.32%) Jharkhand- 635(0.45%) Maharashtra- 238(0.17%) Total- 141589	Up to 2011- 160.653% Predicted to 2019- **186.358%**
10	Brahmani and Baitarani	Jharkhand- 15757 (30%) Orissa- 34749 (67%) Chhatisgarh- 1316 (3%) Total- 50015	Up to 2011- 153.891% Predicted to 2019- **178.514%**
11	Subernarekha	Jharkhand- 13685 (47%) Orissa-11964 (41%) West Bangal- 3547 (12%) Total- 29196	Up to 2011- 163.013% Predicted to 2019- **189.095%**
12	Sabarmati	Rajasthan-4124 (19%) Gujarat- 17550 (81%) Total-21674	Up to 2011- 201.89% Predicted to 2019- **234.193%**
13	Mahi	Madhya Pradesh- 6695 (19%) Rajasthan-16453 (47%) Gujarat- 11694 (34%) Total-34842	Up to 2011- 218.87% Predicted to 2019- **253.89%**
14	West flowing rivers of Kutch and Kathiawar including Luni	Rajasthan-193392 (60.09%) Gujarat-128420 (39.9%) Daman & Diu- 39 (0.01%) Total- 321851	Up to 2011- 221.305% Predicted to 2019- **256.714%**
15	Narmada	Madhya Pradesh- 85172 (86.2%) Maharashtra-1538 (1.56%)	Up to 2011- 209.823% Predicted to 2019- **243.395%**

		Gujarat- 11399 (11.54%) Chattisgarh- 687 (0.7%) Total-98796	
16	Tapi	Madhya Pradesh-9804 (15%) Maharashtra- 51504 (79%) Gujarat- 3837 (6%) Total- 65145	Up to 2011- 188.935% Predicted to 2019- **219.164%**
17	West flowing rivers from Tapi to Tadri	Maharashtra- 32573 (58.22%) Karnataka- 9545 (17.06%) Gujarat- 9666 (17.3%) Goa- 3610 (6.45%) Dadar & Nagar Haveli- 489 (0.87%) Daman & Diu- 57 (0.1%) Total- 55940	Up to 2011- 182.036% Predicted to 2019- **211.16%**
18	West flowing rivers from Tadri to Kanyakumari	Kerala- 35487 (63%) Karnataka- 15550 (28%) Tamilnadu- 4702 (8%) Puducherry- 438 (1%) Total- 56177	Up to 2011- 117.542% Predicted to 2019- **136.349%**
20	Minor river basins drainage to Bangladesh& Burma	Manipur- 14494 (40%) Nagaland- 5606 (15.5%) Mizoram- 14091 (39%) Tripura- 2011 (5.5%) Total- 36202	Up to 2011- 308.122% Predicted to 2019- **357.422%**

From the data available in CWC, It is observed that the average annual percentage loss of gross capacity is 0.72% for 217 Reservoirs and the Observed rate of sedimentation has grossly surpassed the designed rate in all Basins.

Basin	**Average of the Observed/ Designed rate of Reservoir Sedimentation** *(x) indicate the No. of Reservoirs*
Ganga	2.3 (13)
Godavari	0.9 (6)
Krishna	2.32 (15)
Tapi	25.9(3)
Mahanadi	1.28(5)
Overall	5.84(61)

In the study of the 200 Indian Reservoirs, It has been found that Indian reservoirs have experienced annual rate of siltation in live storage zone in range of 0-1% normally, however there are Reservoirs which are at risk and the most risk is in Minor Basins.

Annual Rate of Siltation	>1%	>2%
WFR of Kutch and Saurashtra including Luni	12	3
Cauvery	4	2
Indus	2	3
West Flowing Rivers south of Tapi	1	1
Godavari	1	1
Krishna	5	
Mahi	2	

The Reservoir Age has been the major factor in accumulating the sediments and Reservoirs having an age of more than 25 years are at risk and the Reservoirs with very high capacity show lower rate of sedimentation in all Basins.

5. Sustainable Reservoir Sedimentation as the Invisible Water Source

There is a compiled information for 5700 major / medium dams and barrages in India. These dams occupy approximately 50,000 sq.km area reservoir area and carry an annual storage capacity of 257 BCM. The survey of around 350 Reservoirs in India has been roughly assessed that India loses around 1.5 BCM of Live Storage every year. Though there is no imminent danger of obsoletion of the dams in India in next 50 years, the sedimentation of Reservoirs present an Invisible source of water which can be easily tapped.

Preliminary observation indicate that the minor basins are at grave risk of sedimentation based on many factors. The broad contours however indicate that sedimentation rates in reservoirs are higher than that envisaged at the planning stage and we need an urgent revisit to our design standards. Effective sediment management requires a holistic upstream-downstream inter-relationship. The Desilting, Dredging and Dam Upgradation are the costly solutions and can be a part of the sediment management policy based on the information and reasonable economic analysis for the value of the water that can be saved. For sustainable sediment management it is necessary:

- To measure the erosion rate of the sediments in the basin
- To measure efficiently the sediment load in the Reservoir
- To evaluate the cost of sediment in long term at the time of planning dam structure
- To select most suitable sediment treatment method with consideration of topography and flows of river, effectiveness, economic, environmental and various conditions with overall judgment.
- To apply measures for sediment management with coordination of several reservoirs of basin which may include planning for Sediment **Routing- Sediment Pass Through or Sediment Bye Pass, Sediment Flushing**