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Erosion and sedimentation problems in India

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Abstract The problem of soil erosion is prevalent over about 53% of the total land area of India (Narayana & Ram Babu, 1983). The regions of high erosion include the severely eroded gullied land along the banks of the rivers Yamuna, Chambal and Mahi and other west flowing rivers in western Indian states. In addition the Himalayan and lower Himalayan regions have been greatly affected by soil erosion due to intensive deforestation, large scale road construction, mining and cultivation on steep slopes. Surveys of existing large and medium-sized Indian reservoirs have indicated that at least six large reservoirs (storage > 100 Mm^3) and three medium-sized reservoirs (storage 20-100 Mm^3) have already lost more than 25% of their capacities (Morris, 1995; Shangle, 1991). In the present paper many data related to erosion and sedimentation problems in India are presented. Qualitative analysis of these data is also undertaken to identify the possible causes of intensive erosion and sedimentation. Some of the potential remedial measures are briefly discussed.

INTRODUCTION

Balanced ecosystems comprising soil, water and plant environments are essential for the survival and welfare of mankind. However, ecosystems have been disturbed in the past due to over exploitation in many parts of the world, including some parts of India. The resulting imbalance in the ecosystem is revealed through various undesirable effects, such as degradation of soil surfaces, frequent occurrence of intense floods etc. For example, the large scale deforestation which occurred in the Shiwalik ranges of the Indian Himalayas during the 1960s caused the soil on the land surfaces to be directly exposed to the rains. This unprotected soil was readily removed from the land surface in the fragile Shiwaliks by the combined action of rain and resulting flow.

Vast tracts of land over the country have been irreversibly converted into infertile surfaces due to accelerated soil erosion caused by the above and other factors. These degraded land surfaces have also become a source of pollution of the natural water. Deposition of soil eroded from upland areas in the downstream reaches of rivers has caused aggradation. This has resulted in an increase in the flood plain area of the rivers, in reduction of the clearance below bridges and culverts and in sedimentation of reservoirs.

In the present paper a review and analysis of the problems caused by soil erosion and associated sediment deposition in India is presented. These problems are first discussed in detail. Possible remedial measures are then discussed in brief at the end of the paper.

PROBLEMS CAUSED BY SOIL EROSION

In India a total of 1 750 000 km^2 out of the total land area of 3 280 000 km^2 is prone to soil erosion. Thus about 53% of the total land area of India is prone to erosion (Narayana & Ram Babu, 1983). Areas affected by soil erosion in India can be broadly grouped into two categories, representing, firstly, the Himalayan and Lower Himalayan region and, secondly, other regions.

The Himalayan and Lower Himalayan region

Most parts of the Himalayas, particularly the Shiwaliks which represent the foothills of the Himalayas in the northern and eastern Indian states, are comprised of sandstone, grits and conglomerates with the characteristics of fluvial deposits and with deep soils. These formations are geologically weak, unstable and hence highly prone to erosion. Accelerated erosion has occurred in this region due to intensive deforestation, large scale road construction, mining and cultivation on steep slopes. Approximately 30 000 km^2 have been severely eroded in the northeastern Himalayas due to shifting cultivation (Narayana & Ram Babu, 1983).

Deforestation and associated soil erosion has caused desertification of land in the Shiwalik hills in the Hoshiyarpur district of the Punjab state. The extent of degraded land in this area was 194 km^2 in 1852, 2000 km^2 in 1939, while it increased to 20 000 km^2 in 1981 (Patnaik, 1981). Similarly, large tracts of cultivable land have been abandoned because of the erosion of topsoil in the Kotabagh area of the Nainital district in the state of Uttar Pradesh (Valdiya, 1985). In addition about 45% of the perennial hill springs in these areas go dry during the non-monsoon season because of the reduction in groundwater storage resulting from the erosion of the pervious soil horizons (Valdiya, 1985).

Landslides are the other dominant cause of soil erosion and related problems in the Himalayas. Figure 1 provides a map of the landslide prone areas of India (Garde & Kothyari, 1989). This map indicates that in India landslides mainly occur along the Shiwaliks in the Himalayas. The landslide prone areas also coincide with the locations of high magnitude earthquakes, geological faults and values of the rainfall event ratio (E) which indicate the occurrence of intensive rainfall for long durations. In addition to soil erosion, landslides also cause various other problems, such as the creation of embankments across streams. The breaching of such barriers across streams created by landslides has had disastrous effects, as illustrated by the following example from the Alaknanda valley (Ravindra & Negi, 1982).

An intense thunderstorm over the Alaknanda valley in the Himalayas during 1970 led to severe erosion/landslides and breaching of the barriers which had developed across the Alaknanda River and its tributaries. The sediment load thus increased enormously and the concentration of sediment in the Ganga River at Hardwar (The Alaknanda and the Bhagirathi join at Deoprayag about 80 km upstream of Hardwar to form the Ganga, see Fig. 2) was about 34 000 mg l^{-1}. Thus the Upper Ganga canal which diverts water from the Ganga at Hardwar had to carry a very heavy sediment load. The consequences of the heavy sediment load entering the canal are discussed below.

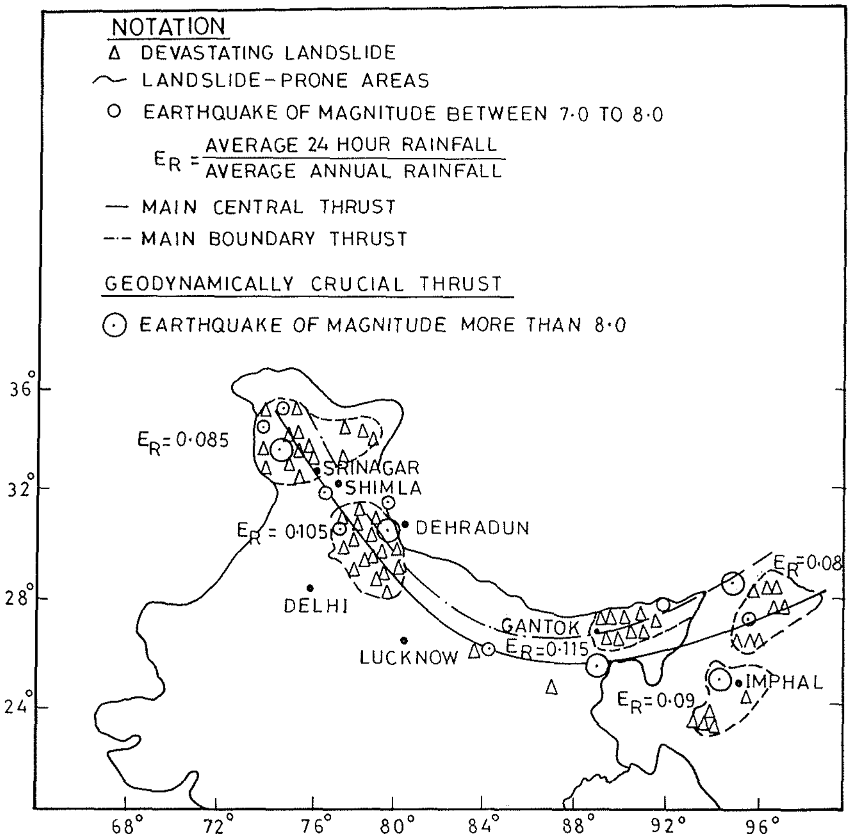

Fig. 1 Map showing landslide-prone areas of India (based on Garde & Kothyari, 1989).

Other regions

The other regions of India affected by sever erosion include the severely eroded gullied lands along the banks of the rivers Yamuna, Chambal, Mahi and other west flowing rivers in Gujarat state and the southern rivers namely the Cauvery and the Godavari river systems. Sheet and rill erosion is the most severe problem in the catchments of these rivers. As a result, agricultural production is greatly affected on the red soils, which cover an area of 720 000 km^2 in the basins of the Chambal and Godavari (Verma *et al.*, 1968). The depth of these soils is limited to 200 mm, in most of these areas. The lateritic soils which are associated with rolling and undulating topography have been found to lose about 4000 t km^{-2} of valuable topsoil annually due to erosion in Peninsular India (Ram Babu *et al.*, 1978).

METHODS FOR ESTIMATION OF SOIL EROSION IN INDIA

Regional estimation of soil erosion is needed for planning and the design of soil conservation measures (Walling, 1988). Such estimates can be obtained through actual

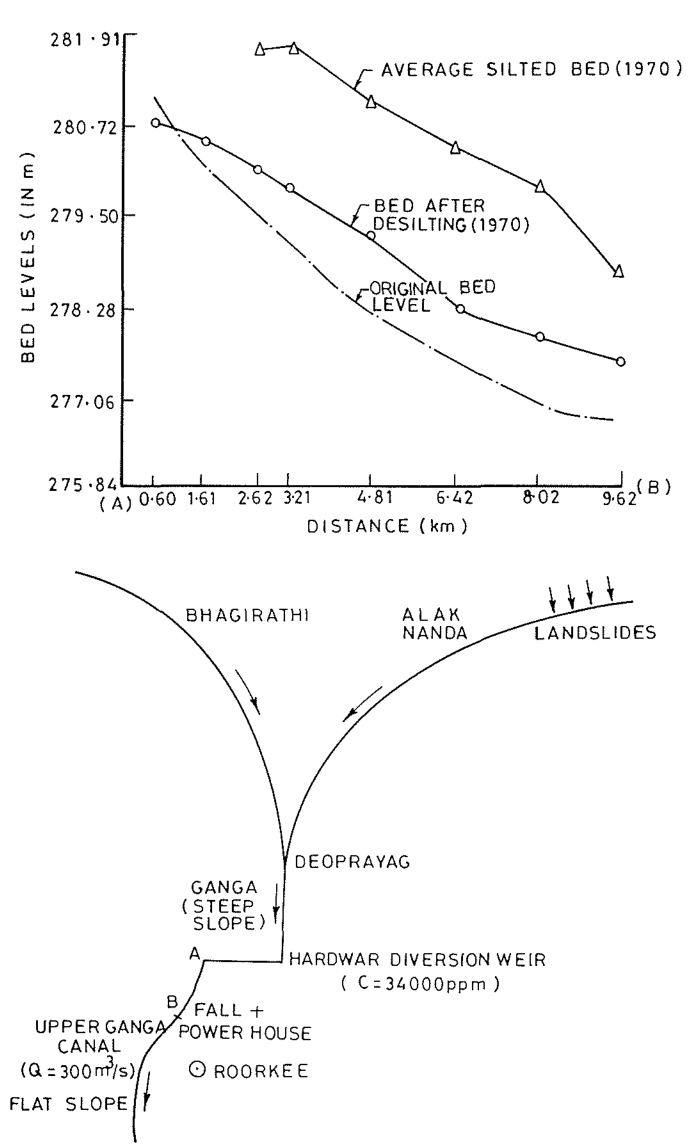

Fig. 2 Aggradation of the Upper Ganga Canal due to overloading (based on Ranga Raju, 1995).

measurements and also through the use of estimation procedures. Surveys for determination of soil erosion rates from catchments and deposition rates in reservoirs are frequently conducted by the various governmental agencies in India (ICAR, 1984; and CBIP, 1981). Measurements of sediment load are made in many rivers across the country by other governmental agencies (CS&WC, 1991; Shangle, 1991). Nevertheless, sediment loads remain ungauged for the majority of the streams, because of the lack of funds. However, the other hydrological data, such as rainfall and runoff, are available for the majority of rivers basins. Estimation procedures can be therefore used to estimate erosion rates for such catchments.

The Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) has been used for estimation of on-site erosion rates. An iso-erodent map of India has been produced based on the erosion index values (Ram Babu *et al.*, 1978), which shows the potential erosivity of rainfall (Singh *et al.*, 1990). Methods have also been evolved for determination of the off-site deposition of eroded soil and the sediment yield from large catchments (Garde & Kothyari, 1987; Narayana & Ram Babu, 1983; Kothyari *et al.*, 1994). However, the most detailed study to date for estimation of sediment yield from large catchments is the work of Garde & Kothyari (1987). An analysis of the data from 50 catchments with areas ranging from 43 km^2 to 83 880 km^2 produced the following equation for mean annual sediment yield:

$$S_{am} = C\, P^{0.6}\, F_e^{1.7}\, S^{0.25}\, D_d^{0.10}\, (P_{max}/P)0.19 \qquad (1)$$

with

$$F_e = (0.8\, F_A + 0.6\, F_G + 0.3\, F_F + 0.1\, F_w)/A \qquad (2)$$

Here S_{am} is the mean annual sediment yield in cm, C is a coefficient depending on the geographical location of the catchment, P is the average annual rainfall in cm, S is the land slope, D_d is the drainage density in km km^{-2}, P_{max} is the average maximum monthly rainfall in cm and A is the catchment area in km^2. F_e is defined as the erosion factor and F_A is the area of arable land in the catchment, F_G is the area occupied by grass and scrub while F_w is the area of waste land and F_F is the forested area.

The data from 154 catchments in India concerning the variables on the right-hand side of equation (1) were also used by Garde & Kothyari (1987) to produce an iso-erosion rate map of India (Fig. 3). The iso-erosion rate map showed that mean annual erosion rates in India vary from 350 t km^{-2} $year^{-1}$ to 2500 t km^{-2} $year^{-1}$. High erosion rate values, as found in the northeastern region, parts of Punjab, UP and Bihar and in certain areas of Andhra Pradesh can be attributed partly to the higher rainfalls in these regions and partly to the geologic conditions and land use. In the absence of any other information, the erosion rate obtained from Fig. 3 can be used for planning purposes. Considering the fact that out of the variables affecting the erosion rate, as indicated by equation 1, only the rainfall variable changes from year to year; the following equation has been proposed for the estimation annual erosion rates from catchments (Garde & Kothyari, 1987).

$$S_a = C\, F_e^{1.7}\, S^{0.25}\, D_d^{0.10}\, (P_{max}/P)\, P_a^m \qquad (3)$$

Here S_a is the annual erosion rate in cm, P_a is annual rainfall in cm and m is the exponent. The value of m was found to be related to the coefficient of variation of annual rainfall as per Fig. 4.

PROBLEMS DUE TO SOIL DEPOSITION

The soil eroded and transported from headwater catchments can be deposited at downstream points in the river, causing many problems. For instance, a bridge

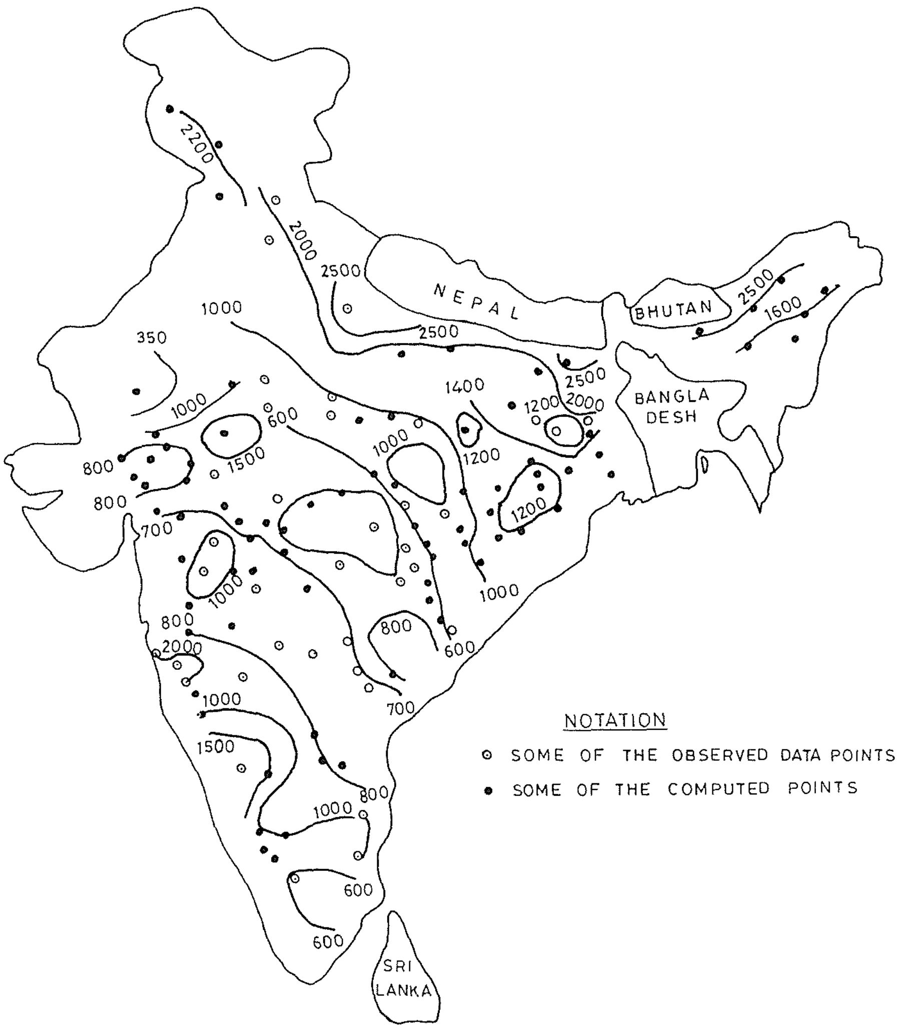

Fig. 3 Erosion rates in India. The iso-erosion lines refer to annual erosion rates in t km^{-2} $year^{-1}$ (based on Garde & Kothyari, 1987).

constructed in 1919 over a torrent crossing the Dehradun-Mussoorie road, in the northern state of UP originally had a clearance of 16.7 m below its soffit. In 1941, when the bridge was resurveyed, aggradation of about 12.2 m had taken place in the torrent bed, due to the excessive erosion/landsliding in the upstream catchment. Subsequently, further deposition of 4.5 m occurred causing a complete choking of the clearance below the soffit (Garde & Kothyari, 1989). Similarly, heavy aggradation occurred in the neighbouring Baldi stream (See Fig. 5) due to deposition of sediment eroded from its catchment (CS&WC,1987).

The heavy sediment load which entered the Upper Ganga Canal taking off from the River Ganga at Hardwar (see Fig. 2) resulted in about 0.17 Mm^3 of sediment deposition over a 10 km reach stretching from its headworks during a period of about one day. The average depth of deposition was found to be 2.1 m and of the order of half the depth of

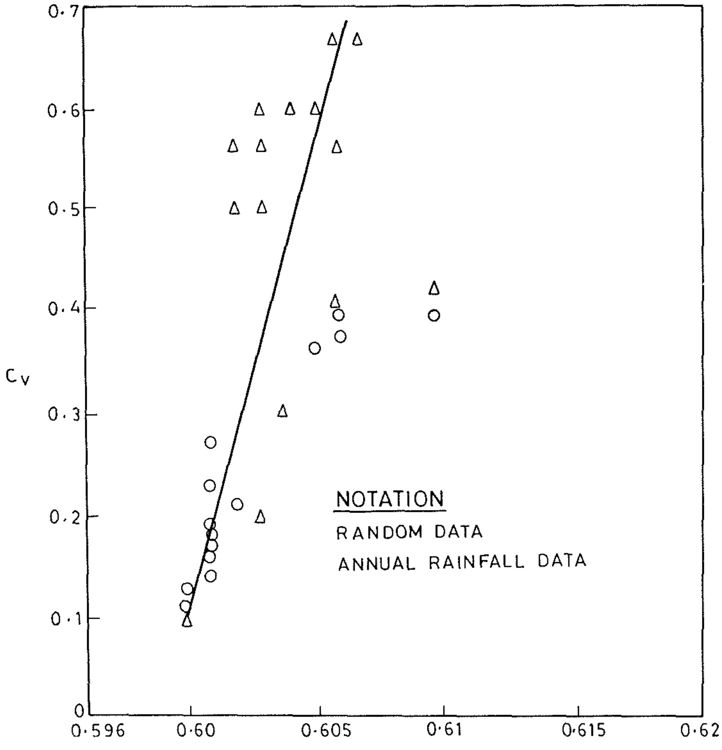

Fig. 4 Variation of *m* with C_v (based on Garde & Kothyari 1987).

flow. The removal of deposited material necessitated the closer of the canal for two months during the growing season, which entailed a huge expenditure (Ranga Raju, 1995).

The sedimentation of reservoirs continues to remain the most important problem resulting from soil erosion in catchments. About 126 dams which are 30 m or more in height had been completed in India for irrigation, hydropower generation, flood control etc., before the year 1971. Many of these dams now contain significant accumulations

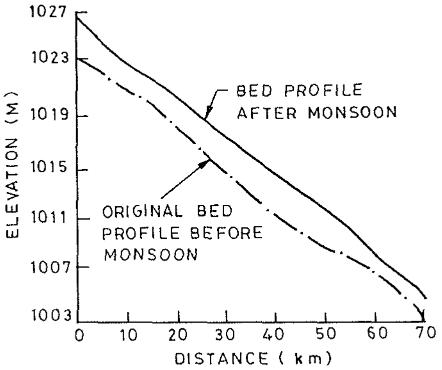

Fig. 5 Change in the bed profile of the River Baldi during the monsoon of 1984 due to a landslide in its catchment (based on CS&WC, 1987).

Table 1 Reservoir sedimentation rates in India (based on Morris, 1995).

Reservoir	Year of construction	Catchment area (km^2)	Reservoir volume (mm)	Sedimentation rate (mm year^{-1})	50% capacity lost (year)	Life of reservoir (years)
Srirama Sagar	1970	91 750	35	0.62	1998	56
Nizamsagar	1930	21 694	39	0.64	1960	61
Matatila	1956	20 720	55	0.44	2018	124
Hirakud	1956	83 395	97	0.66	2030	147
Girna	1965	4 729	129	0.80	2045	161
Tungabhadra	1953	28 179	133	1.01	2019	132
Panchet Hill	1956	10 966	137	1.05	2021	130
Bhakra	1958	56 980	172	0.60	2101	287
Maithon	1955	6 294	218	1.43	2031	152
Lower Bhavani	1953	4 200	222	0.44	2205	504
Mayurakshi	1954	1 860	327	1.63	2054	201
Gandhisagar	1960	23 025	336	0.96	2135	350
Koyna Dam	1961	776	3 851	1.52	3228	2533

of sediment eroded from their catchments. Analysis of the sedimentation data (Shangle, 1991; Murthi, 1977) indicate a wide range of sedimentation rates in these reservoirs. For example, for some large reservoirs, such as the 2.4×10^9 m^3 Ram Ganga reservoir in UP, the data indicate a very small rate of sedimentation, while the 3.1×10^9 m^3 Srirama Sagar reservoir in Andra Pradesh was found to have lost 25% of its capacity during the first 14 years of impounding. Table 1 provides a compilation of the reservoir sedimentation rates estimated by of various investigators.

Based on a screening analysis of the available data, Morris (1995) concluded that few reservoirs in India have lost as much as 50% of their capacity to date. By 2020 it was expected that 27 of the 116 reservoirs will have lost half their original capacity and by the year 2500, only about 20% of India's existing reservoirs will not have lost 50% of their capacity (see Fig. 6).

REMEDIAL MEASURES

The general problems due to soil erosion and deposition illustrated above are worldwide problems and not restricted to India. However for sustainable development it will be essential to thoroughly understand and solve these problems. For this purpose, a detailed screening analysis should first be carried out to identify areas of severe erosion and sedimentation sites. A greater number of streams will have to be gauged to determine their sediment loads. Also, detailed reservoirs surveys will have to be carried out. Next, priority catchments and reservoirs may be selected for experimentation to study the effectiveness of soil conservation measures and reservoir operation policies. Finally the

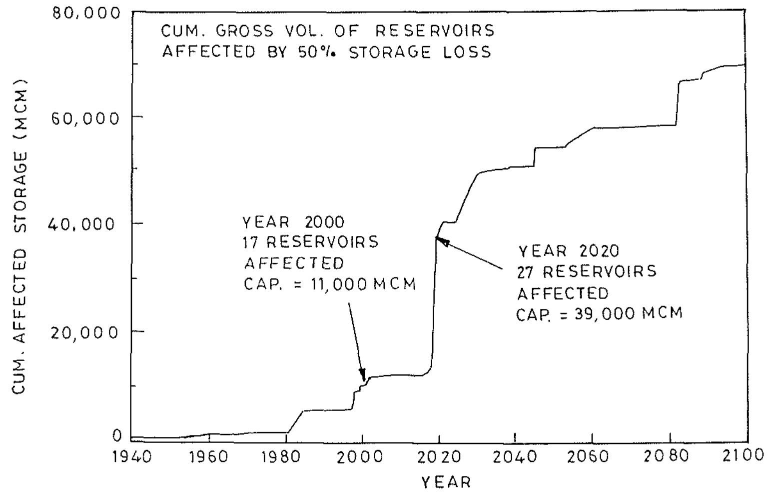

Fig. 6 Total original capacity of the Indian reservoirs which will be seriously affected by sedimentation (50% storage loss), plotted as a function of time (based on Morris, 1995).

technology thus developed for sediment management could be transported by expanding these sediment management activities to the other catchments and reservoirs.

Various programmes for soil conservation are currently receiving high priority in India. However, it seems to be a difficult task to control erosion over vast tracts of lands by soil conservation practices alone. Nevertheless, the problem of reservoir sedimentation can be brought under control by construction of upstream sediment traps and by evolving effective procedures for sediment routing and sediment removal from existing reservoirs.

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