

Chapter 5

Dams, Riparian Settlement and the Threat of Climate Change in a Dynamic Fluvial Environment

A Case Study of the Damodar River, India

Kumkum Bhattacharyya and Michael J. Wiley

Abstract The Damodar River, a subsystem of the Ganga, has always been flood prone. People as well as governments throughout the centuries have dealt with the caprices of this vital water resource, using structures such as embankments, weirs, barrages and dams. Post-independence the Damodar Valley Corporation (DVC) constructed four multipurpose dams to facilitate regional development and reduce flood hazards. Post-dam hydrographs show decreased monsoon discharges, reduced peak flow and a shifting of peak flow from July to August to September. Despite the DVC dams, the lower valley is still vulnerable to flooding, because the transport capacity of the river has also been reduced. As a result, the frequency of bank full events today is again similar to that observed in the pre-dam period. Because of the control structures once mobile channel *char* lands have been stabilised and permanently settled by Bangladeshi refugees. These new riparian communities are threatened by the fluvial environment. Changing patterns in riparian land use, fostered by alterations in flow regime, coupled with the long-term prospect of increased rain variability due to climate change, appear to be increasing the risk of rare but devastating floods in the Lower Damodar.

Keywords Char lands • Climate change • Communities • Dams • Damodar Valley Corporation • Fluvial environment • Hydrology • Geomorphology • Water resources

K. Bhattacharyya, Ph.D. (✉)
Department of Geography, University of Central Arkansas, 302 B Irby Hall,
Conway, AR 72035, USA
e-mail: kumkumb@uca.edu

M.J. Wiley, Ph.D.
School of Natural Resources and Environment, University of Michigan,
G 166 DANA, 440 Church St., Ann Arbor, MI 48109, USA
e-mail: mjwiley@umich.edu

5.1 Introduction

Finding environmentally sustainable approaches to river management nowadays has become more urgent than ever before, particularly with regard to understanding the perennially controversial impact of dams both on the fluvial systems and on the socio-economic environment. The need to apply scientific knowledge for economic and social benefit has been strongly felt in developing countries (of the tropics) since the early 1940s, and worldwide dam management issues have increasingly captured scientific attention in recent decades (Williams and Wolman 1984; Petts 1984; WCD 2000; EP/EC 2000; Chin et al. 2002; Molle 2006; Wiley et al. 2008, 2010; Grantham et al. 2008; Bhattacharyya 2011).

River water was one of the first natural resources to be exploited, and almost all major rivers in decolonised Latin American, Asian and African countries are now controlled. In India as elsewhere, River Basin Organisations (RBOs) first arose as a mechanism for the integrated planning of large water development projects, aimed at meeting growing requirements for power, irrigation and industry. At the same time governments and RBOs promised technological relief from flood hazards, which had massive and tragic impacts on riparian communities on a regular basis. Offering the twin benefits of increased productivity and decreased environmental hazard, the integrated development of many river basins was subsequently pursued throughout the world (White 1977; Saha 1981; Saha and Barrow 1981). In newly constituted India, one of the first such RBOs, the Damodar Valley Corporation (DVC), was founded in 1948; it was modelled on the Tennessee Valley Authority (TVA) of the United States (Chandra 2003; Pangare et al. 2009). The unalloyed benefits of river control measures, however, are no longer taken for granted. Floods still wreak havoc (Kundzewicz and Kaczmarek 2000; Kundzewicz and Schellnhuber 2004) and troubling ecological consequences worldwide (Doyle et al. 2003). The debate surrounding this issue, unfortunately, has become extremely polarised. River control structures have thus become social, economic and political issues.

Within the last decade, in particular, river resource management policy has undergone a major paradigm shift (Pahl-Wostl et al. 2007). The older ideas of river basin planning gradually intermingled with watershed and ecosystem management approaches (Molle 2006; Wiley et al. 2008) and were adjusted accordingly. The European Union's Water Framework Directive (WFD) defines a new strategy for meeting human needs while protecting the environment that is relevant to other regions of the world (EP/EC 2000; Grantham et al. 2008). From this perspective, a review of the first Indian multipurpose river valley project and its human and environmental impact through dam construction is timely. This study reports on changes over approximately a 70-year period focusing primarily on hydro-geomorphological and social consequences of flow regime alterations and channel modifications in the Lower Damodar River valley. It also reviews from the social perspective both impressive gains in development since the DVC began its work and longer-term changes in flood hazard, particularly with an eye on future climate changes. Lessons learned from this case study may be helpful in guiding the planning and management of rivers of a similar nature in India and elsewhere.

It is offered as a contribution to the larger study of sustainable watershed planning and the search for ways to meet growing global water demands in an ecologically sustainable manner (EP/EC 2000; Wiley et al. 2008, 2010; Grantham et al. 2008).

5.2 The Damodar River System

The Damodar River is a subsystem of the Ganges River system of India. It rises in the Chotanagpur watershed approximately at $23^{\circ} 37' N$ and $84^{\circ} 41' E$ and the geographical boundary of the basin lies between $22^{\circ} 15' N$ to $24^{\circ} 30' N$ and $84^{\circ} 30' E$ to $88^{\circ} 15' E$. The catchment area of the river is about $22,000 \text{ km}^2$ of which about $19,000 \text{ km}^2$ are in uplands and $3,000 \text{ km}^2$ in plains of a deltaic nature. The length of the river is 541 km approximately. The river slope is 1.86 m/km for the first 241 km , 0.57 m/km the next 167 km and 0.16 m/km in the last reach. The main tributaries are the Barakar, Tilaiya and Konar. Below the confluence of the Barakar and Damodar, there are a few minor tributaries such as the Nunia and Sali. Once the main distributaries were the Khari, Banka, Behula and Gangur, but now they are all disconnected, independent rivers. Near Palla the river takes a sharp southerly bend. Below Jamalpur, the river bifurcates into the Kanki-Mundeswari and the Amta channel and joins the Hooghly (also spelled Hugli) at Falta some 48.3 km south of Kolkata (also spelled Calcutta). This study is concerned with the reach of the Damodar River below the confluencing outlets of the Maithon and Panchet reservoirs and the old confluence point with the Hooghly River, as these two lower dams have an enormous impact on the downstream fluvial environment (Fig. 5.1).

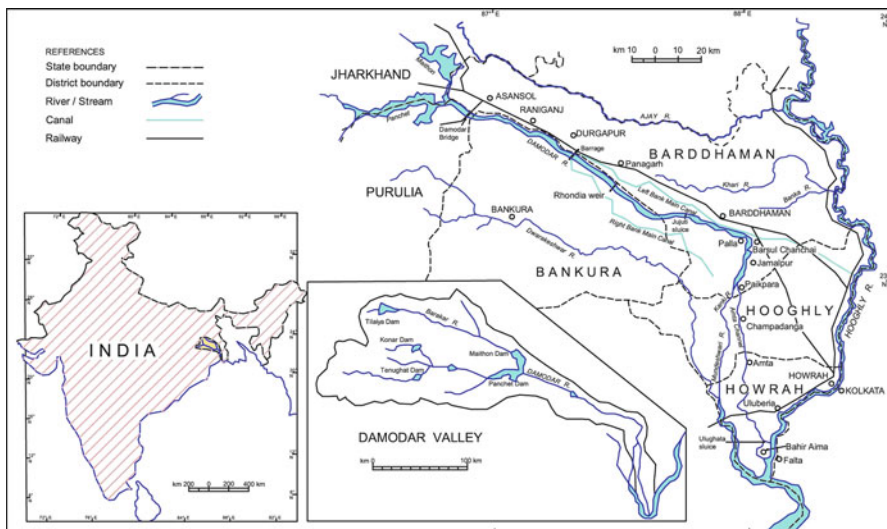


Fig. 5.1 Location of the studied part of the Damodar River

Above the reservoirs, the Damodar flows through the quartz-rich Archaean gneiss. Below, the Damodar flows through the sandstone-rich Gondwana sedimentaries near Asansol and Raniganj, which provide a rich source of fluvial sediments. The Damodar is a naturally flood-prone river. Gauge records at Rhondia (~95 km below Panchet; upstream catchment area) are extensive and relatively complete since 1933. Maximum flood discharge (recorded in 1913, 1935 and 1941) was 18,678 m³/s at Rhondia. Average annual daily and minimum daily discharge for the period of record is 268 and 0 m³/s, respectively. Floods in the river are the cumulative effect of rainfall on the catchment and the dynamics of catchment storage and channel transport. The nature of the river channel itself is especially important in this case, since aggrading beds and gradual shrinkage of cross-sectional areas and conveyance are increasing proneness to flood (Sen 1985a, b).

5.3 Methodology and Database

For a comparative analysis of the changes in the flow regime of the Lower Damodar River, data from 1933 to 2010 (according to availability) have been divided into two periods, the pre-dam period between 1933 and 1956 and the post-dam period between 1959 and 2010. It is worth mentioning that the lower dams Maithon and Panchet are fully functioning since 1957 and 1959, respectively.

Data were collected from different sources. To analyse the flow regime of the Damodar River, hydrological data from the following sources have been used: the Hydraulic Data Division, the Damodar Valley Corporation and the Central Water Commission, at Maithon, Jharkhand, and the Irrigation and Waterways Department, the Government of West Bengal and the Damodar Canals No. 11, Subdivision-Rhondia at Bardhaman. Hydrological data are also available in published form from the record of UNESCO (1971a, b, 1979, 1985) and from the report of the National Commission on Flood (GoI 1980). Geographical data sources included Survey of India (SoI) maps, cadastral maps and 2003 LISS-3 scenes of IRS-ID satellite image. The Dickens' map surveyed in 1854 (1:126,720) was also used. Frequent field visits were conducted to collect data on land use and riverbed landscape characteristics as these are significant issues in this study. During these visits residents were interviewed to obtain local perspectives on hydrogeomorphic changes, land management practices and river flooding.

Frequency analyses of flow and flood data were performed using USACE Hydrologic Engineering Center (HEC) DSS 2.01 and SSP 1.01 software (<http://www.hec.usace.army.mil/>). Daily flow data (summarised from hourly gauge records) were available for representative 10-year periods before and after dam construction. Longer-term annual peak flow data records were also available. We analysed both sets of data collected from the Rhondia gauging station independently. Dominant discharge analysis was based on total suspended sediment and flow samples taken at the Damodar Bridge site, located below the lower dams.

5.4 History of Flooding

In old records the Damodar has always been referred to as a river of sorrow. Flood propensity of the river is reflected in the construction of extensive embankments over 4,000 years ago as referred by hydraulic engineer Kapil Bhattacharyya (1959) and in sixteenth- to seventeenth-century maps (Fig. 5.2, Sen 1962; Bhattacharyya 1998, 2011).

The first recorded flood occurred in 1730 (Voorduin 1947). Floods with a peak flow of 8,496 m³/s or more occurred 37 times between the years 1823 and 2007. The floods of 1823, 1840, 1913, 1935, 1941, 1958, 1959 and 1978 had peaks of more than 16,992 m³/s. A peak flow of about 18,678 m³/s was recorded in August 1913, August 1935 and again in October 1941 (DVC 1995; Bhattacharyya 2011). In an early report on flooding and embankments in this area by Sage et al. (1846), 13 severe inundations took place over a time span of 115 years, with seven inundations occurring in the first 85 years and six in the last 30 years. This increase in flooding may be attributed to the fact that, in the earlier period,

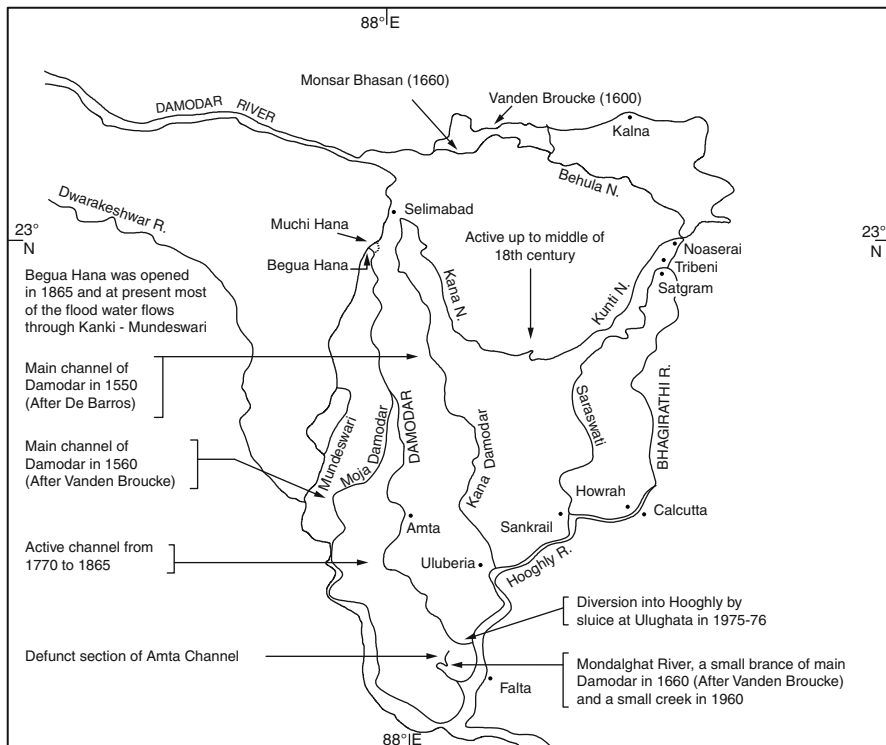


Fig. 5.2 Changing courses of the Damodar River (After Sen 1962; Basu 1989; Bhattacharyya 2002)

overflow irrigation from the Damodar was considered beneficial for agriculture, and people built and maintained canals to carry floodwater to their fields. From 1815 onwards, however, landlords and tenants of central Bengal started to neglect the irrigation canal systems, presumably beginning during the Maratha-Afghans war (1803–1818). The British thought these waterways were for navigation only and left them as they were. As these deteriorating waterways or canals took in lower amounts of water, more water remained in the Damodar main channel, and it grew to be a menace to the riparian tract (Willcocks 1930; Bhattacharyya 2011). Eventually the entire riverine regime of Bengal, Bihar and Orissa was transformed from a flood-enriched agrarian area into a landscape vulnerable to devastation by floods (D'Souza 2006).

5.5 Controlling the Lower Damodar

The flood-prone Damodar River has encouraged the construction of control structures from very ancient times; however, most traces have been destroyed completely due to the shifting of rivers (Fig. 5.2). The current embankments along the Damodar River were most probably constructed by local landlords to protect their land and property from floods (Gastrell 1863; Sengupta 1951) and certainly date from a period before British rule (O'Malley and Chakravarti 1909). The report of the embankment committee formed in 1846 states that these embankments were irregular and elevations were uncertain. The maintenance of embankments was inefficient and neglected (O'Malley and Chakravarti 1912), and breaching of embankments was a regular phenomenon. Several subcommittees were formed to investigate these issues (Bhattacharyya 1998, 2011). It was finally concluded that the removal of the right embankment for about 32.2 km would provide complete security to the left bank, which included the town of Bardhaman, the East India railway line and the populous districts of Hooghly and Bardhaman. In 1889 another 16.1 km of the right bank embankments was removed (Voorduin 1947). The left bank embankments were made continuous for a length of 176.87 km and were provided with many sluices. Attempts were also made to transfer excess water from the Damodar River to some of the decaying distributaries through the Eden canal in 1881. In 1933, the Damodar Canal system was opened. Water from the main river was admitted into the canal with the help of a weir at Rhondia near Panagarh of the district of Bardhaman.

Despite all of these measures, the river was flooding the lower sector throughout the British period (1908–1946). Concern about the devastation wreaked by the Damodar reached its peak in 1943, after one of the severest floods. Finally, after India won independence, the Damodar Valley Corporation (DVC) was founded on July 7, 1948. The project had originally envisaged the construction of eight dams and the planner estimated a design flood of 28,321 m³/s with a 100-year frequency. To protect the lower valley, it was estimated that the design flood be moderated to 7,080 m³/s, which was the total capacity of the Lower Damodar. However, due to

Table 5.1 DVC infrastructure – at a glance

DVC command area	24,235 km ²
<i>Power management</i>	
Total installed capacity	2,796.5 MW
Thermal power stations	4, Capacity: 2,570 MW
Hydel power stations	3, Capacity: 147.2 MW
Gas turbine station	1, Capacity: 82.5 MW
Substations and receiving stations	At 220 kV: 11 At 132 kV: 33
Transmission lines	At 220 kV: 1,342 km At 132 kV: 3,419 km
<i>Water management</i>	
Major dams and barrages	Tilaiya, Konar, Maithon and Panchet dams and Durgapur barrage
Irrigation command area (gross)	569,000 ha
Irrigation potential created	364,000 ha
Flood reserve capacity	1,292 million m ³
Canals	2,494 km
<i>Soil conservation</i>	
Forest, farms, upland and wasteland treatment	400,000 ha (approximately)
Check dams	16,000 (approximately)

Data source: DVC, Kolkata

financial and other constraints, the participating governments of West Bengal, Bihar (present Jharkhand) and the central government approved the construction of only four multipurpose dams (Voorduin 1947; Bhattacharyya 1998, 2011).

The DVC constructed the dams of Tilaiya and Maithon on the Barakar River, a tributary of Damodar, in 1952 and 1957, respectively; the Konar dam on the Konar tributary in 1955; and the Panchet dam on the Damodar River itself in 1959 (Tables 5.1 and 5.2). Maithon and Panchet act as control reservoirs and are located approximately 8 km above the confluence point of the Barakar and the Damodar Rivers. The construction of a barrage at Durgapur was started in 1952 and subsidiary structures were completed by 1958. The Tenughat Dam was constructed by the Government of Jharkhand in 1978 on the Damodar River; it was designed primarily for industrial and municipal water supply uses as well as for irrigation through the Tenu-Bokaro Canal.

5.5.1 Downstream Impact of Dams on the Hydrologic Regime

The retention of water behind a dam and its gradual release downstream result in the reduction of peak storm flows and an alteration of the entire flow and sediment

Table 5.2 DVC power plants – at a glance

Name	Location	Existing capacity	Commissioning
<i>Hydel</i>			
Tilaiya	River: Barakar Dist.: Hazaribagh State: Jharkhand	4 MW (2 × 2 MW)	U-I Feb. 1953 U-II Jul. 1953
Maithon	River: Barakar Dist.: Bardhaman State: West Bengal	63.2 MW (2 × 20 MW + 1 × 23.2 MW)	U-I Oct. 1957 U-II Mar. 1958 U-III Dec. 1958
Panchet	River: Damodar Dist.: Dhanbad State: Jharkhand	80 MW (2 × 40 MW)	U-I Dec. 1959 U-II Mar. 1991
Total hydel		147.2 MW	
<i>Thermal</i>			
Bokaro 'B'	Dist.: Bokaro State: Jharkhand	630 MW (3 × 210 MW)	U-I Mar. 1986 U-II Nov. 1990 U-III Aug. 1993
Chandrapur	Dist.: Bokaro State: Jharkhand	750 MW (3 × 130 MW + 3 × 120 MW)	U-I Oct. 1964 U-II May. 1965 U-III Jul. 1968 U-IV Mar. 1974 U-V Mar. 1975 U-VI Mar. 1979
Durgapur	Dist.: Bardhaman State: West Bengal	350 MW (1 × 140 MW + 1 × 210 MW)	U-III Dec. 1966 U-IV Sep. 1982
Mejia	Dist.: Bankura State: West Bengal	840 MW (4 × 210 MW)	U-I Mar. 1996 U-II Mar. 1998 U-III Sept. 1999 U-IV Feb. 2005
Total thermal		2,570 MW	
<i>Gas turbine</i>			
Maithon	Dist.: Dhanbad State: West Bengal	82.5 MW (3 × 27.5 MW)	U-I Oct. 1989 U-II Oct. 1989 U-III Oct. 1989
Grand total		2,799.7 MW	

Data source: DVC, Kolkata

regimes (Williams and Wolman 1984; Petts 1984; Chien 1985; Kondolf 1997; Kondolf and Batalla 2006; Batalla et al. 2004; Graf 1999, 2006; Richter et al. 2010). The Damodar River was no exception. Based on gauging at Rhondia, before the DVC dams were constructed, about 35 % of the annual rainfall on the upstream basin was carried as flow through the lower river (Fig. 5.3, Table 5.2).

Since construction in 1957–1958, river flow at Rhondia has been substantially reduced to on average 23 % of catchment precipitation by both increased evaporation from the reservoirs and increased consumptive use of the stored water during dry periods. The representative daily average streamflow for the Damodar at

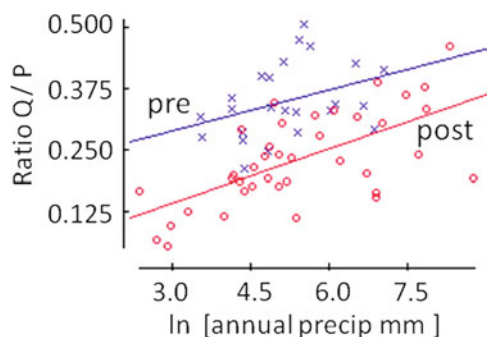


Fig. 5.3 Proportion of annual rainfall delivered as river flow at Rhondia before and after DVC dam construction (Data source: DVC, Maithon) (Note: More than a century of rainfall data from a large number of gauges distributed within the Upper Damodar Valley, which includes the Maithon and Panchet sub-catchments, are available from DVC, Maithon. Rainfall data for the monsoon seasons between 1891 and 2007 for both sub-catchments has been assembled and analysed)

Table 5.3 Summary of pre- and post-dam construction hydrology as measured at Rhondia

		Annual precipitation (mm)	Average daily flow (m ³ /s)	Q/P ratio	Annual peak Q (m ³ /s)	Return interval (years)	Dominant Q (m ³ /s)	Bank full return (years)
Pre-dam (before 1957)	Mean	1,118	327	0.35	8,655	2.32	2,178	1.03
	SD	187	97	0.08	3,977	–	–	–
	Min	843	172	0.21	1,714	1.01	–	–
	Max	1,660	492	0.51	18,406	>500	–	–
	Years	67	24	24	30	–	–	–
Post-dam (after 1958)	Mean	1,155	234	0.23	3,646	1.36	720	1.06
	SD	259	128	0.09	2,321	–	–	–
	Min	644	32	0.05	344	1.01	–	–
	Max	1,714	623	0.46	10,919	231	–	–
	Years	47	42	39	53	–	–	–
Contrast		NS	<.001	<.001	–	–	–	–

Upstream catchment: 8,837 km² (approximately). Ratio of cumulative annual river flow to cumulative catchment precipitation (Q/P) reflects proportion of precipitation delivered annually as river flow at Rhondia. Estimated dominant discharge is the expected equilibrium channel capacity at bank full and was calculated at the discharge from daily flow records and pre- and post-dam sediment loading functions (see Fig. 5.4)

Rhondia was 327 m³/s in the pre-dam and 234 m³/s in the post-dam period. Overall, the flow regime after the construction of the dam had higher baseflows but lower storm flows (Table 5.3), reflecting the additional storage capacity of the reservoirs and the reduced upstream catchment yields.

Average annual flood flows likewise declined (58 %) after the DVC projects were completed although there were again large interannual differences driven by variation in monsoonal precipitation. Frequency analysis (Table 5.4) suggests

Table 5.4 Frequency analyses for pre- and post-dam flow at Rhondia gauge

Daily average flow			Annual peak flow			
EF	Pre-dam	Post-dam	EF	Pre-dam	Post-dam	Return time
(%)	1940–1950	1993–2008	(%)	1933–1957	1959–2010	(years)
	(m ³ /s)	(m ³ /s)		(m ³ /s)	(m ³ /s)	
1	3,575	2,460	0.2	17,682	11,542	500
5	1,977	1,139	0.5	16,950	10,742	200
10	1,263	681	1	16,271	10,029	100
20	577	322	2	15,456	9,209	50
30	200	168	5	14,104	7,926	20
40	85	99	10	12,797	6,772	10
50	38	66	20	11,129	5,415	5
60	19	37	50	79,126	3,164	2
70	9	16	80	50,529	1,577	1.25
80	3	6	90	3,816	1,024	1.11
85	0.7	2	95	2,9517	691	1.05

Data source: Damodar Canals No. 11, Subdivision-Rhondia, Barddhaman; GoI 1980; UNESCO 1971a, b, 1979, 1985

EF exceedance frequency (% of time the flow indicated is equaled or exceeded in the period of record)

Note: The daily streamflow (discharge) data from 1940 to 1949 at Rhondia, situated approximately 95 km downstream of Panchet Dam and 21 km from the Durgapur barrage, has been collected from the Damodar Canals No. 11, Subdivision-Rhondia, and the same data for 1993 to 2007 has been computed from hourly streamflow data available from the same location. The monthly average and minimum streamflow of the Damodar River at Rhondia from 1934 to 1979 have been collected from UNESCO (1971a, b, 1979, 1985). Data for the years 1961 to 1964, 1968, and 1975 are not available. The monthly average streamflow of the river at Rhondia for the period 1982–2007 has been calculated from the daily streamflow available from the Damodar Canals No. 11, Subdivision-Rhondia at Barddhaman. The annual peak streamflow data for the River Damodar at Rhondia are available from 1823 to 1933 as a discontinuous series from GoI (1980). The same data from 1934 to 1960 are published by UNESCO (1971a, b) and from 1960 to 2010 are available from the Damodar Canals No. 11, Subdivision-Rhondia, Barddhaman

that at Rhondia flood magnitudes of 8,000 m³ and larger, once common (~2-year recurrence interval), have become relatively rare (<15 recurrence interval). And flood flows >12,000 m³ have been entirely eliminated to date (pre-dam recurrence interval <10 years). In terms of reducing annual flood flow magnitudes, the DVC projects have been extremely successful. The capacity of the DVC system to moderate flood flows is impressive and is summarised in Table 5.5.

The discharge of the Damodar at Rhondia for four climatologic seasons with respect to the total annual flow from 1934 to 2007 is given in Table 5.6. The most important characteristic to note is that there has been at least a 30 % decrease in average annual discharge from the pre-dam to the post-dam period but also a nearly 48 % increase in flow variability. In contrast to the reductions seen during the monsoon, winter and summer flows have been substantially increased, and their variability has declined. After the dam closure monsoon water has been stored and

Table 5.5 Performance of Damodar Valley Reservoirs (Maithon and Panchet) in combined flood moderation during major flood periods^a

Periods	Combined peak inflow (1,000 m ³ /s)	Moderated outflow (1,000 m ³ /s)	Flood moderation (1,000 m ³ /s)	Flood moderation achieved
Sep. 1958	15.7	5.0	10.7	68
Oct. 1959	17.6	8.2	9.5	53
Oct. 1960	9.9	2.6	7.2	73
Oct. 1961	14.6	4.6	10.1	68
Jul. 1963	12.8	3.4	9.4	73
Oct. 1963	13.2	2.6	10.6	80
Sep. 1971	12.0	5.1	6.9	58
Sep. 1973	16.7	5.0	11.7	70
Sep. 1978	21.9	4.6	17.3	79
Sep. 1995	17.5	7.1	10.4	59
Sep. 1999	10.3	3.4	6.9	67
Sep. 2000	10.8	5.7	5.3	47
Sep. 2006	14.4	6.9	7.5	52
Sep. 2007	11.1	7.5	3.6	32

Data source: DVC 1995, MRO office, DVC Maithon

^aExamination of maximum inflow and maximum outflow data for the two lower dams at Maithon and Panchet shows that flood moderation has been achieved during major flood years. Detailed examination of flow data, as available at Rhondia, revealed that maximum flow of 18,408 m³/s had occurred twice in August 1913 and 1935 before the implementation of the DVC, but data shows that major floods nearing or exceeding this maximum observed flood of 18,406 m³/s occurred during 1959, 1978 and 1995 and were successfully checked

Table 5.6 Seasonal streamflow characteristics of Damodar at Rhondia in pre-dam (1934–1956) and post-dam (1959–2007) periods (% of streamflow with respect to annual average streamflow total)

Period	Parameter	Summer	Monsoon	Autumn	Winter	Mean annual total (m ³ /s)
Pre-dam	Years	21	21	21	21	—
	X	1.40	83.70	12.23	2.60	4,061.05
	SD	1.32	7.04	6.49	2.27	1,186.90
	CV	94.29	8.41	53.07	87.31	29.23
Post-dam	Years	48	48	48	48	—
	X	5.07	75.58	14.60	5.22	2,836.02
	SD	6.67	13.81	12.11	4.58	1,587.34
	CV	131.56	18.27	82.95	87.74	55.97

Data source: Damodar Canals No.11, Subdivision-Rhondia, Bardhaman

X average % of flow, SD standard deviation, CV coefficient of variation

Summer Mar–May, Monsoon Jun–Sep, Autumn Oct–Nov, Winter Dec–Feb

released during the non-monsoonal periods (i.e. summer, autumn and winter) to the Durgapur barrage, from which water is diverted to irrigation canals. Increasing demand for irrigation water has further enhanced the non-monsoon flow to some extent. Thus, there is considerable augmentation of flow in the lean season to

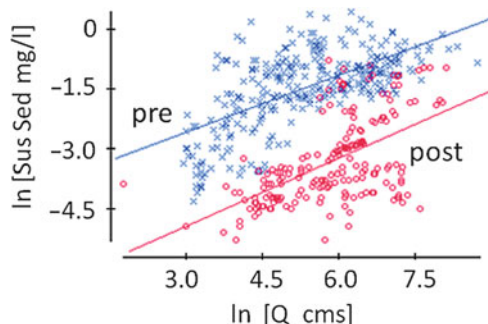


Fig. 5.4 Suspended sediment load pre- and post-dam construction at Damodar Bridge (Data source: DVC, Maithon) (Note: Information about suspended sediment concentration for the period 1952–1955 and 1981, 1984, 1985, 1986, 1987, 1988, 1991 and 1996–2001 have been computed from daily average suspended sediment concentration data provided by the Hydraulic Data Division DVC, Maithon)

meet the non-monsoon demand for irrigation. An irrigation system dependent on rainfall and river discharge has been replaced by more dependable irrigation through regulated release from reservoirs.

5.5.2 *Changing Channel Morphology and Sandbar Formation*

As the hydrologic conditions in the Damodar catchment have been modified through the development of control structures, the lower river channel system itself has been radically changed. Morphological changes along the Damodar River post DVC dam construction include both severe aggradation and narrowing of the channel through lateral accretion. Since the construction of the dam, the Damodar channel has undergone a general narrowing due to decreases in the flow and reductions in dominant discharge (Table 5.2, Fig. 5.4). The channel bed has been aggraded at an alarming rate in some places, whereas the volume of sediment and rate of sedimentation have grown in other areas. Although sediment is trapped in the reservoirs, the river still receives a million tons of sediment from the uncontrolled sectors below the dams in the Raniganj coalfield region. The declining capacity of the river to transport this sediment has made the channel bed a sediment sink with a downstream series of growing sandbars (locally known as *char* lands or *mana*). This effect is further enhanced by the coarsening of bed material. In some sections the Damodar channel has been reduced due to excessive sediment deposition following the flood of 1978. Channel reduction appears to have been achieved by the accumulation of sediment as shoals that are now vegetated and stabilised with agricultural fields and human settlements.

Sand loads carried by the Damodar have always given rise to sandbars within the river channel. Surveys by Captain C. H. Dickens' (1853) and SoI maps surveyed between 1929 and 1930 show that back then several semi-transient mid-channel and

semi-mobile marginal bars covered with grass jungles existed. From 1947 onwards, after the partition of India and the former East Pakistan (present Bangladesh), refugees from Bangladesh began to occupy the sandbars. Encroachment on the *char* lands has continued to the present day due to the more hydrologically secure riparian environment created by multipurpose DVC projects. These anthropogenic landforms have acquired their present shapes and can be identified after construction of the Durgapur barrage (1958) and the Maithon (1957) and Panchet (1959) reservoirs. Some sandbars have merged with main land and most of the sandbars are populated. From the topographical sheets surveyed from 1985 to 1986, 2003 LISS-3 scenes of IRS-ID satellite image and from field visits during the period of 2007 to 2008, it is evident that new sandbars have emerged, although some have also been destroyed by channel migration.

Today, between the Maithon and Panchet reservoirs and the Falta outfall 250 km downstream, there are 23 larger occupied sandbars or *char* lands and a series of point bars. These *char* lands are now used as a resource base mostly by refugees who have matched land use at fine scales to flood experiences, applying their own concept of flood zoning to the riverbed and effectively assessing short-term and long-term risks.

5.5.3 Social Consequences of Dams: Examples from Human-Induced Fluvial Environment

Human alterations of the river's flow regime have resulted in the emergence of a series of stable sandbars that now characterise the Damodar River below the Maithon and Panchet dams. The local people did not identify the resource potentialities of these sandbars, since historically they were inundated and geomorphically ephemeral. These *char* lands remained as a stock of potential settlement sites. Refugees analysed the 'new' land more positively and responded rationally by considering it as a boon to their independent existence. The riverbed landscape at present is a result of functional relations that have developed between the riverbed and its occupiers (Bhattacharyya 1998, 2011). West Bengal received a large number of refugees after Indian independence with a fresh influx of Bangladeshi refugees after the Bangladesh War of 1970. In both phases a significant number of Bangladeshi refugees selected the riverbeds of West Bengal, including those of the Lower Damodar, as their second home. To illustrate the types of interactions that have occurred between river processes and riparian communities, we focus here briefly on two specific examples (Fig. 5.5).

Examples: Ramakrishna Palli, Pallishri and Sitarampur Mana

The Ramakrishna Palli, Pallishri squatters' colony and Sitarampur Mana are sited on a marginal but complex sandbar system below the Durgapur barrage. Pallishri

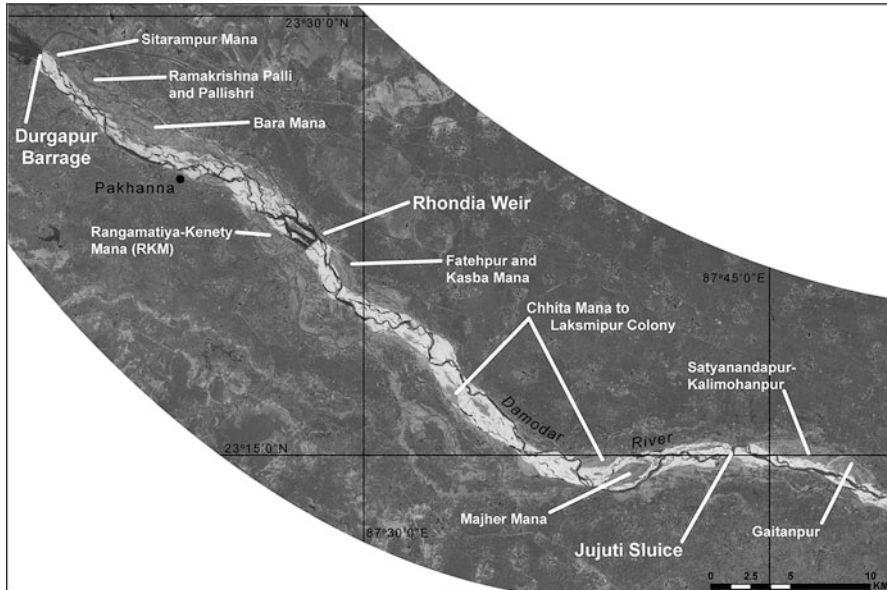


Fig. 5.5 Distribution of the sandbars below the Durgapur barrage showing the specific sandbars studied (Details of satellite image: Landsat ETM+; WRS2 Path: 139, Row: 04; Date of Pass: 19 March 2008)

used to be a squatters' colony but the residents have now been granted land deeds. Rivers are natural boundaries often taken as demarcating lines between countries, states and districts. Political boundaries usually remain static within a short time horizon and may be used to identify the shifting nature of a river.

Changes in generalised land use characteristics and landscape can be observed (Fig. 5.6). The bar material varies from fresh sand to clay; the clay deposits occur near former and current channel positions (e.g. D₂, D₃, D₄). Clay-bearing soils are significant, since they facilitate rice paddy culture. Multiple cropping is a common practice in this alluvial bar, and the dried-up portion of D₃ is used for double cropping since clay deposits of the dried-up channel are good for cultivating rice. This indicates that the people are aware of the deposition of clay materials in decaying channels and the higher field capacity of clay soil. Additional crops are grown on the bed of D₄ and in adjacent areas. These are unauthorised agricultural fields. Almost all types of vegetables, oilseeds and cereals are grown on these sandbars. Comparatively infertile lands are used for the cultivation of a coarse variety of jute (*mesta*). The oilseeds grown on these sandbars are mustard and sesame. Cereals like rice, wheat and many types of vegetables are also grown here.

Figure 5.7 shows hydromorphological characteristics, land use, and landscape features that include the channels of D₁, D₂, D₃, D₄ and D₅. The emergence of new sandbars and areas of double and multiple cropping are depicted. The main Pallishri settlement is located further from the channel D₁ at a higher elevation. This part

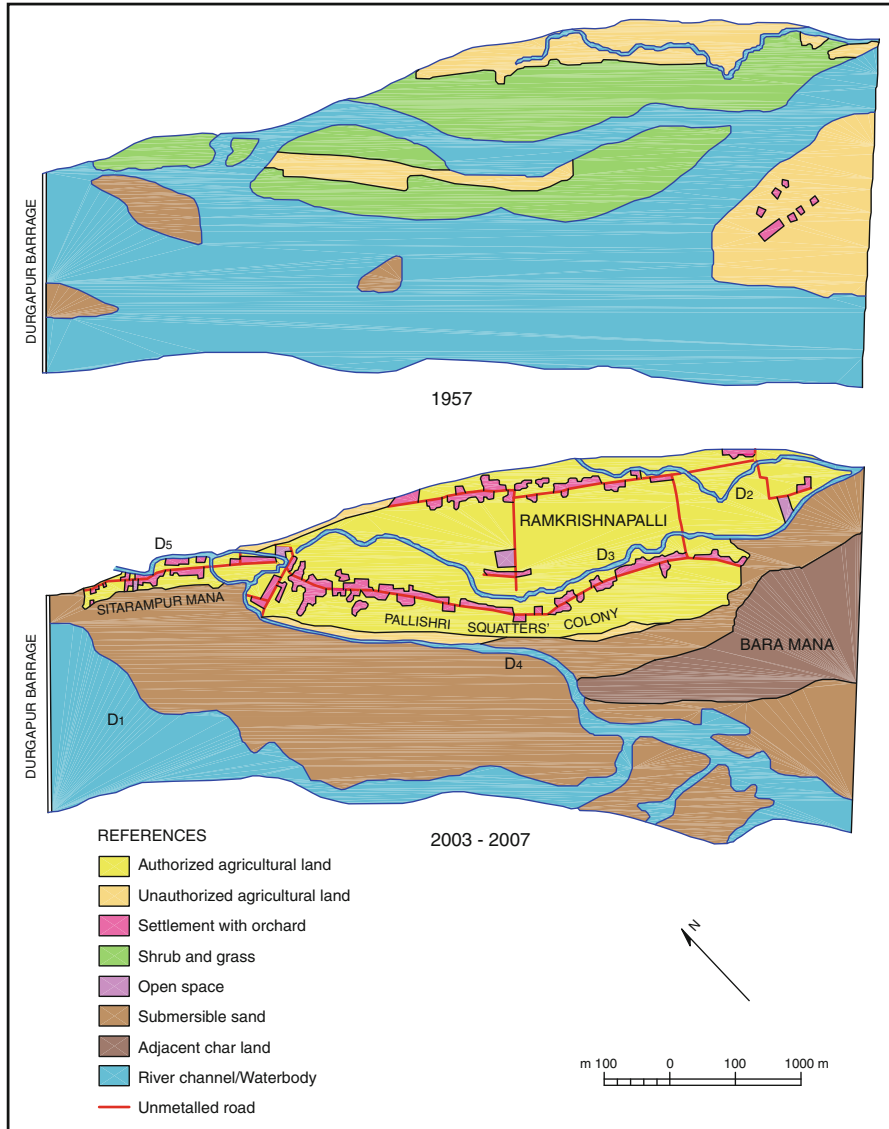
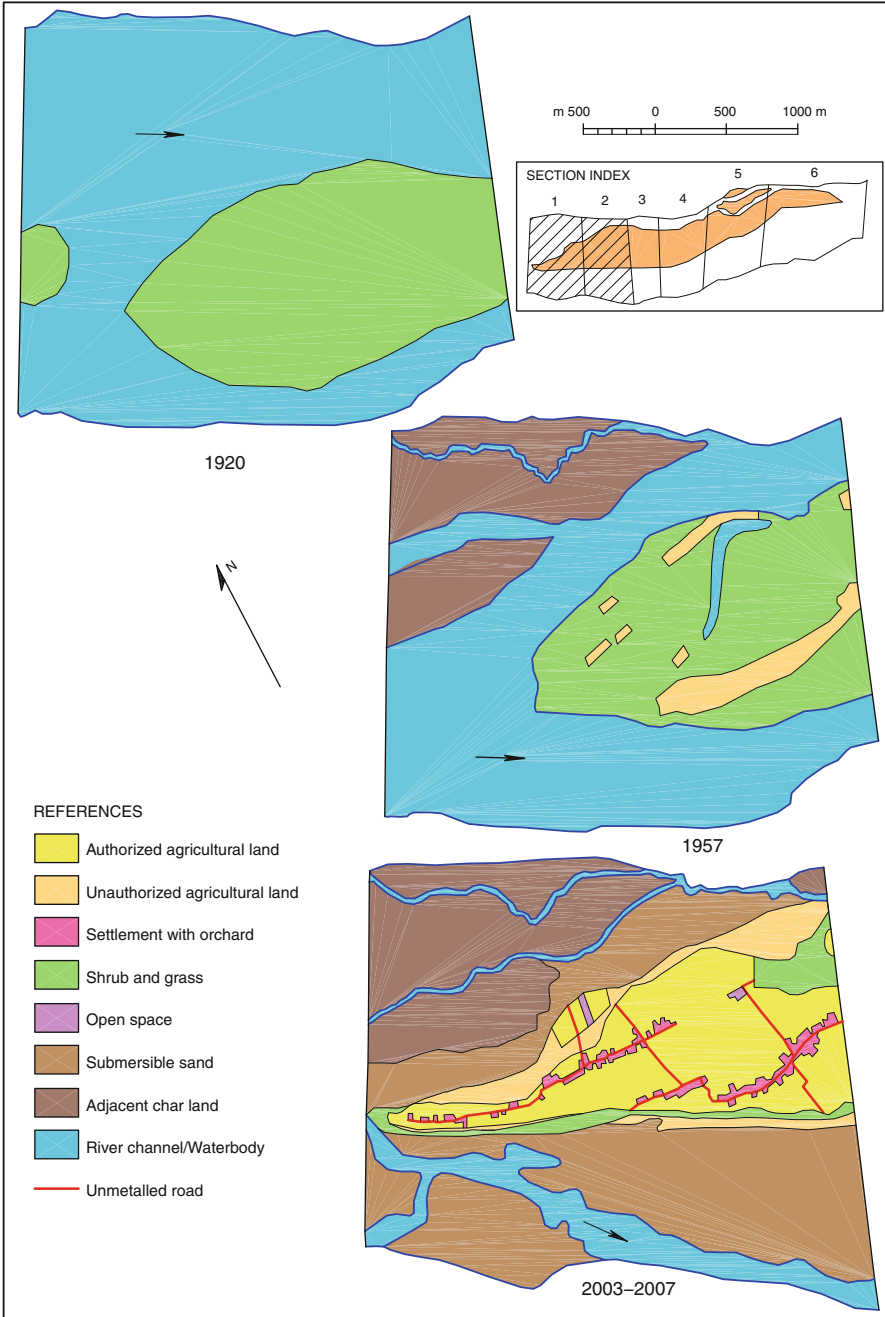


Fig. 5.6 Sitarampur Mana, Ramkrishna Palli, and Pallishri squatters' colony: changes in generalised land use characteristics and landscape (Note: Map prepared from cadastral or Mouza maps, Survey of India (SoI) maps of 73M/7N.W. (1:25,000), 73M/7 (1:50,000), 2003 LISS-3 scenes of IRS-ID and layout plans prepared between 1996 and 1998 and modified in 2007. Details of satellite image: IRS-ID, Sensor: LISS-3, Resolution: 23.5 m, Date of Pass: 23 January 2003, Path: 107, Row: 55, Bands: Green, Red, NIR & SWIR)



of Pallishri, incidentally, has been the most stable part of the sandbar since 1957. Ramkrishna Palli is located close to the district boundary. The Sitarampur Mana is an extension of the Pallishri colony. The village roads are running almost parallel. In fact, village roads follow the boundary line between agricultural plots, particularly towards the south-western part of Pallishri.

The current riverbed landscape shows diversity at micro-level. Sociocultural, economic and political backgrounds of the riverbed communities are reflected in land use practices. The identification of resources and their utilisation and conservation depend on resource perception. The resource potentialities of the *char* lands were not perceived initially by the local people. This remained as a stock of fundamental geomorphic entities. The perception of the migrant communities has been controlled by their low position in the social space. Land use in the *char* lands follows the dictate of micro-relief on the one hand and perceived environment of the riverbed occupiers on the other (Bhattacharyya 1998, 1999, 2011).

Example: Bara Mana

Bara Mana, the largest alluvial sandbar in the culturally defined Lower Damodar, is sited below the Durgapur barrage. To review the changes in generalised land use characteristics and landscapes, Bara Mana has been divided into six sections, two of which are shown in Fig. 5.7. Over the last decades, the grass-covered land has been turned into agricultural fields. On the cadastral maps of 1957, some unauthorised agricultural fields can be found; permanent settlements developed after 1958 and 1959, upon completion of Durgapur barrage and Maithon and Panchet reservoirs. Section 1 comprising Bamandihi Mouza is shown in Fig. 5.8, which served as reference for the following observations:

1. Grasses are allowed to grow on the erosion-prone bank.
2. Jute is cultivated in the adjacent zone.
3. Double cropping is a common feature on the extreme west of Bamandihi.
4. Additional crops are grown in the unauthorised plots towards the north.
5. Multiple cropping is practised on higher land above the inundation level.
6. Linear settlements are to be found on higher ground in the flood-free area.
7. Linear settlements of low density are observed in inundation-prone areas towards the west. This part of the bar is also devoid of irrigation facilities.



Fig. 5.7 Bara Mana (*sections 1 and 2*), changes in generalised land use characteristics and landscape (Bamandihi and Purakonda Mouza) (Note: Maps prepared from cadastral maps, 2003 LISS-3 scenes of IRS-ID satellite of Indian National Remote Sensing Agency (NRSA), Hyderabad. Cadastral Survey (CS) maps (Bamandihi, Purakonda), surveyed between 1917 and 1924, and Revision Survey (RS) maps surveyed between 1954 and 1957 and several layout plans originally prepared between 1996 and 1997 and modified between 2007 and 2008 have been used. Mouza maps have been collected from District Collectorates. Survey of India (Sol) maps of 73M/7N.E., 73M/7N.W., 73M/7S.E. (1:25,000), 73M/7 (1:63,360, 1:50,000), IRS Geo-coded imagery 73M/7 and satellite image of 1994 IRS IB LISS-2 FCC classified image 1:100,000 have been consulted)

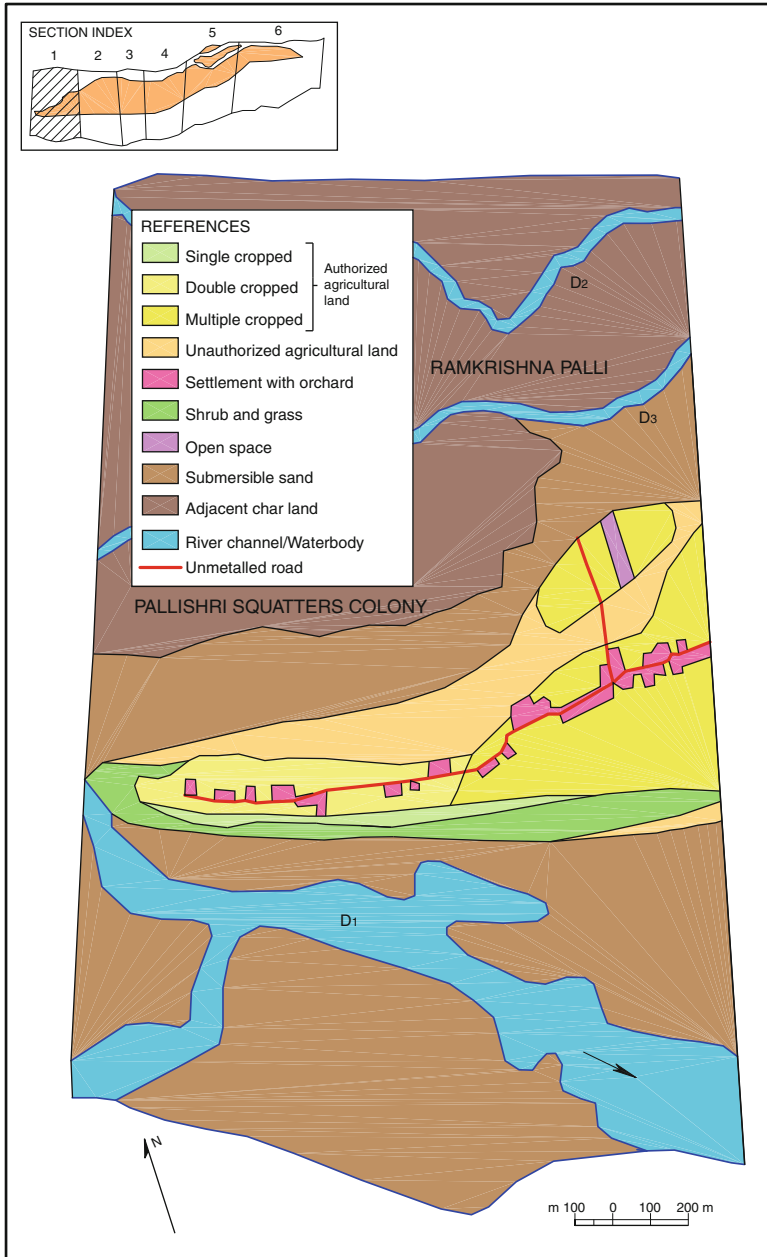


Fig. 5.8 Bara Mana (section 1) land use characteristics Bamandihi Mouza (Note: Map prepared from layout plans of Bamandihi Mouza prepared between 1996 and 1998 and modified in 2007 and through active field survey)

Early on, migrants began to perceive the agricultural potential of the sandbars as they came originally from farm sectors adopting themselves to similar tracts with wet rice culture. Bolai Paik, a well-known farmer from Bara Mana, reported that farmers first used this tract as grazing grounds. Falling leaves and animal droppings enhanced the fertility of the sandbars. Land use on the sandbars follows the dictate of micro-relief. The crop calendar is finely adjusted to match the flood-prone micro-environment. In higher parts of the stable sandbars above inundation level, settlement sites are found with individual huts on a higher plinth. The settlements are aligned strikingly linear along the crest of the convex bars. In these higher parts of the bars, perennial tree crops have been introduced, as well as floriculture and silkworm rearing mulberry cultivation. The zone between the higher tract and the inundation level is used for cultivating cash crops, cereals and vegetables. Inundation-prone areas are used to grow additional crops. Where habitation is not possible due to the low height of the bars, sand quarrying has become a dominant activity. Moreover, settlers often take the risk of growing capital-intensive vegetables even in the most vulnerable tract, as ready markets are present in Barddhaman and Durgapur. On these sandbars the groundwater table is high and a crop is assured with irrigation through shallow pumps. Present land uses such as the site and structural pattern of settlements, site and selection of crops and mode of irrigation water are very carefully attuned to the best utilisation of the local resource base (Basu and Bhattacharyya 1991; Bhattacharyya 1998, 2011).

5.6 Discussions and Conclusions

The natural resources and landscapes of the planet nowadays are controlled mostly by anthropogenic forces rather than natural forces (Turner et al. 1990; Messerli et al. 2000), a dynamic that has led to the suggestion that the current geological epoch be renamed ‘Anthropocene’ in place of ‘Holocene’ (Crutzen and Stoermer 2000; Ehlers 2008 cited in Baghel and Nüsser 2010; Zalasiewicz et al. 2008). The Damodar River has been controlled by government and hydraulic communities throughout the centuries, by employing both macro- and microscale planning and variously scaled river training programmes: embankments, canals, sluices, weirs, dykes, barrages, dams and reservoirs are now viable components of a historically conditioned geomorphic landscape (Bhattacharyya 1998, 2011). The Damodar’s geo-fluvial landscape, therefore, like other major rivers of the world today, is largely anthropogenic in character.

We believe that the Damodar River control project has been clearly beneficial in terms of regional, economic and social development (Tables 5.1 and 5.2). The thermal power plants supply electricity to the region and have encouraged substantial industrial growth in nearby cities. Irrigation has also been drastically increased (Bhattacharyya 2002). Human settlers, taking advantage of reduced flooding and newly emerging *char* lands, have further augmented the resource potential of the river by building local control structures and carefully planning their own land use strategies (Bhattacharyya 1999, 2011). For the riverbed settlers of the

Damodar River, as noted by Wolman (2007, pers. com.), ‘... land use, cropping and settlement patterns, at a micro level, represent a sophisticated understanding of the flood regime and opportunities to maximise the productive capacity of an unpromising environment’.

However, while the promise of economic development appears to have been realised by river control, the promise of reduced flood hazard has proven more elusive. Geomorphological processes ensured that channel shape configurations would over time be adjusted to the new hydrologic regime initiated by the DVC developments. Today, although the magnitudes of annual floods have been reduced significantly, the frequency of over-bank flooding is approaching that of the pre-dam period. Channel aggradation, driven by flow reductions, has produced a new equilibrium between flow and sediment loading which retains the much observed relationship between channel capacity, flooding and annual floods with a return frequency of 1.2–1.5 years. However, years of flood suppression following the construction of the reservoirs and the predictably reduced flow rates have encouraged wholesale settlement of *mana* and in recent years even encroachment in the main channel itself.¹ As a result, the question must be whether the risks of catastrophic flooding losses have in fact increased in the long run as a result of what was originally conceived of as a flood control project. Riparian communities today find themselves in a clearly more vulnerable position when large events occur (e.g. 1978) than ever before.

Given that to assess the flood hazard both frequency and vulnerability have to be taken into consideration, it is interesting to ask what role the past 50 years of flood suppression may have played in promoting future vulnerability. Linking considerations of the hydrologic, geomorphic, and social consequences of dam construction can lead to a very different assessment of the potential hazards than using the more traditional focus on flood hydrology alone. This clearly is an argument for the kind of integrated water resources management perspective now being promoted across much of the WFD (see EP/EC 2000; Grantham et al. 2008; Pangare et al. 2009). Reviewing the history of floods and flood control in the Lower Damodar, it is clear that doing away entirely with floods is neither possible nor desirable. The goal should be not to eliminate floods but to incorporate them within our water management strategy, as with ‘flushing floods’ (DVC 1957) or Environmental Flow Requirements (EFRs), which deal with the amount, timing and conditions under which water should be discharged from the dams to retain the natural integrity of the downstream river ecosystem (Bergkamp et al. 2000). Controlled releases could be maintained without excessive flooding of the populated *char* lands with the goal of sustaining sufficient channel capacity to carry many common floods of frequent recurrence.²

¹Biswas, P. Personal communication through phone conversation, dated 7 May 2011, a farmer of Bara Mana, located at the Damodar River.

²Wolman, M. G. Personal communication through letter dated 10 April 2006 and an e-mail/letter dated 11 January 2007, Late Professor, Department of Geography and Environmental Engineering, The Johns Hopkins University, Baltimore, MD, USA, pp 21218–2686.

The most crucial problem in the Lower Damodar, however, is that of anthropogenic encroachment and attempts at stabilisation of the active riverbed by the riverbed occupiers. Encroachment can both contribute to higher flood peaks by reducing hydrologic storage (Kundzewicz and Kaczmarek 2000) and increase the damages caused by flooding by increasing the population's vulnerability. The fact that most of the riverbed occupiers are Bangladeshi refugees makes this a critical regional and political issue. Increasing demand for living space and food creates a pressure to utilise hazard zones, including flood-prone areas (Bird 1980). So it is not unlikely that riverbeds in India and other countries, particularly in tropical countries, may be occupied by permanent settlements and transient sandbars may become immobile causing channel deterioration. These are problems that were not anticipated when the DVC was planned (Bhattacharyya 2011). Active riverbeds, high-flow channels and floodplain wetlands should be delineated and settlements on active channel should be discouraged, both as a matter of conservation and of public health and welfare.

5.6.1 The Need for Integrating Watershed Science and Management

Policymakers working in the domain of flood and water resource management are faced with the enormously challenging task of parsing vast amounts of data and, perhaps most importantly, understanding the complex dynamics of physical, biological and social subsystems related to the river environment. To arrive at rational decisions that will affect the lives and livelihoods of millions calls for a truly outstanding ecological understanding in the most general sense of the word ecology.

The scope and scale of these problems put a premium on developing accessible decision support systems suitable to link scientific databases, modelling analyses and geographic information systems (GIS) processing. GIS is already widely used in the field of flood and river resource management (Correia et al. 1998) and more recently in studies of the impact of sea level rise due to climate change on coastal communities (Dasgupta et al. 2009). Collaborative exploration of alternate management scenarios using GIS-based frameworks can be an essential component of linking government policy and action with academic expertise and local stakeholder interests (Burrough and McDonnell 1998; Stevenson et al. 2008; Wiley et al. 2008). Some of the important matters to be addressed on the Damodar include how much water do we now have in the river catchment, how much are we using and how much will we need later (Maidment 2002). These questions were also posed by M. Gordon Wolman (Kobell 2007). Therefore, there is an urgent need to compile and update flood- and water-related data and to make them systematically available to all stakeholders by computerisation. GIS can play a key role in making the data and their analysis explicable to both managers and the public, integrating them into a

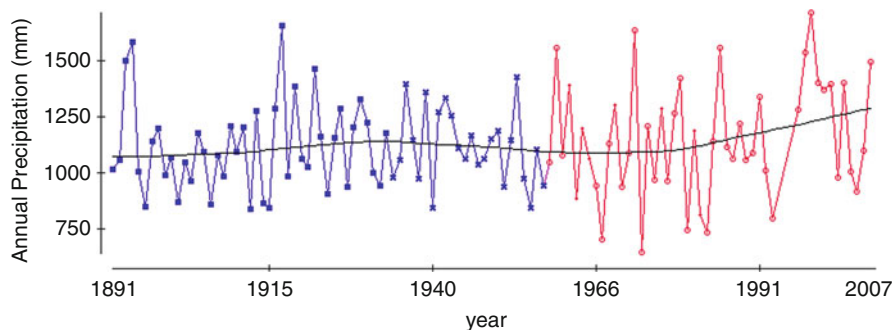


Fig. 5.9 Long-term trends in annual precipitation for combined catchments above Maithon and Panchet. Solid points (*blue*) are pre-DVC dam construction, open points (*red*) are post-dam (Data source: DVC, Maithon)

public and participatory conversation about the future. The European Union's Water Framework Directive (EP/EC 2000) provides a useful example of a framework for building the capacity of communities to conduct long-term planning at the basin-scale and manage water resources in a more deliberate and efficient manner.

Climate change potentially introduces a new and ominous feature into the functional relationship between river control practices and flood hazard, at least on the Damodar. Anticipated increases in the mean and variance of precipitation and floods in this region (Roy and Mazumdar 2005) are consistent with observed monsoon rainfall patterns in the upper Damodar catchment (Fig. 5.9) and with increases in the variability of flood flows observed post 1958. If the trajectory of the regional climate is indeed towards more extreme precipitation patterns, flood hazard will be potentially even more severe in the coming years as channel conveyance capacity continues to equilibrate to low post-dam flow and sediment regimes while extreme events nevertheless increase in magnitude. 'It's something that's been neglected, hasn't been talked about and it's something the world will have to do./.../Adaptation is going to be absolutely crucial for some societies' (Rajendra Pachauri, chairman of the Intergovernmental Panel on Climate Change, cited in Borenstein 2009). In other words, growing water consumption, hydrological, land use and climatic change acting together ensure that our rivers as well as our watersheds will face a future of rapid ecological change.

To prepare for the future, risks and options need to be effectively communicated with and effectively explored by stakeholders as well as by decision-makers at multiple levels of governments and across the Damodar Valley Corporation. Our goal should be the establishment of coherent basin-wide, integrated analytical frameworks for both hydrologic/ecological and social impact forecasting (e.g. Wiley et al. 2010). Such a framework could make use of extensive use of GIS technologies to both perform analyses and effectively communicate with the regional stakeholders. The risks and uncertainties inherent for communities living in close symbiosis with a river system are vast. Natural flood hazards and variability in

geomorphic process are combined with complex social processes and larger-scale forces of climate change, regional land cover transformation and a changing political will for expanding and/or maintaining the existing engineering infrastructure. Changes in land use and climate along with hydro regime management scenarios should be quantitatively evaluated and graphically communicated, thus providing a unified basis for local and regional discussions on preparation and mitigation. The development of such a capacity would place the Damodar Valley Corporation (DVC) and its hydraulic society at the forefront of national water resource and climate change planning and policy development.

Acknowledgements We are thankful to K. K. Chakraborty (Ex Manager Reservoir Operation (MRO), DVC Maithon) and A. K. Pal (Damodar Canals No. 11 Subdivision-Rhondia) for providing valuable data. Several surveyors of RR&RD (Refugee Relief and Rehabilitation Department) at Bankura have provided data for generating land use maps. It would be a long list if we had to acknowledge within this short campus all those villagers who became friends during the field survey at various stages. We appreciate your generous help.

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